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Instruction Handbook for



50 MHz

AIL Type 136

PART NUMBER 214111

PRECISION TEST RECEIVER

68-10-07-07



July 1966

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SECTION 1. INTRODUCTION

The AIL Type 136 Precision Test Receiver is a laboratory test instrument whose primary function is to accurately measure signal-level changes. AIL Part number 214111 is a combination of Type 136 components modified for use at 50 MHz and consists of special versions of the parts numbered 13610, 13630, 03130, and 203393. Among its many applications are:

1. Calibration of RF and IF attenuators and directional couplers,
2. Calibration of signal-generator output attenuators,
3. Measurement of noise figure,
4. Measurement of gain and linearity characteristics of RF and IF amplifiers,
5. Measurement of transmission and selectivity characteristics of RF and IF components (isolators, tuners, power dividers, etc.).

Information on other standard type 136 components is included in this handbook for reference purposes.

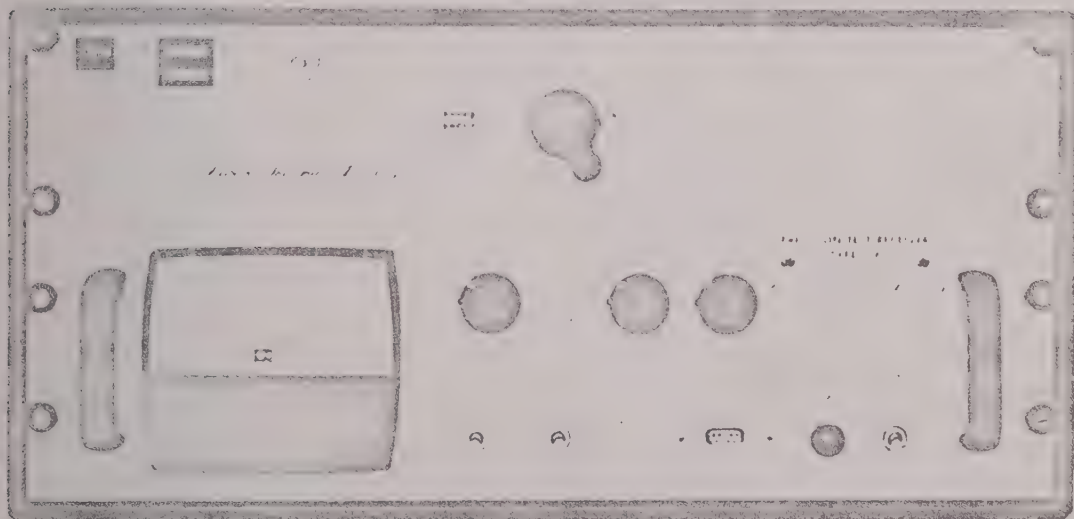


FIGURE 1. TYPE 136 PRECISION TEST RECEIVER,
P/N 214125 (50 MHz)

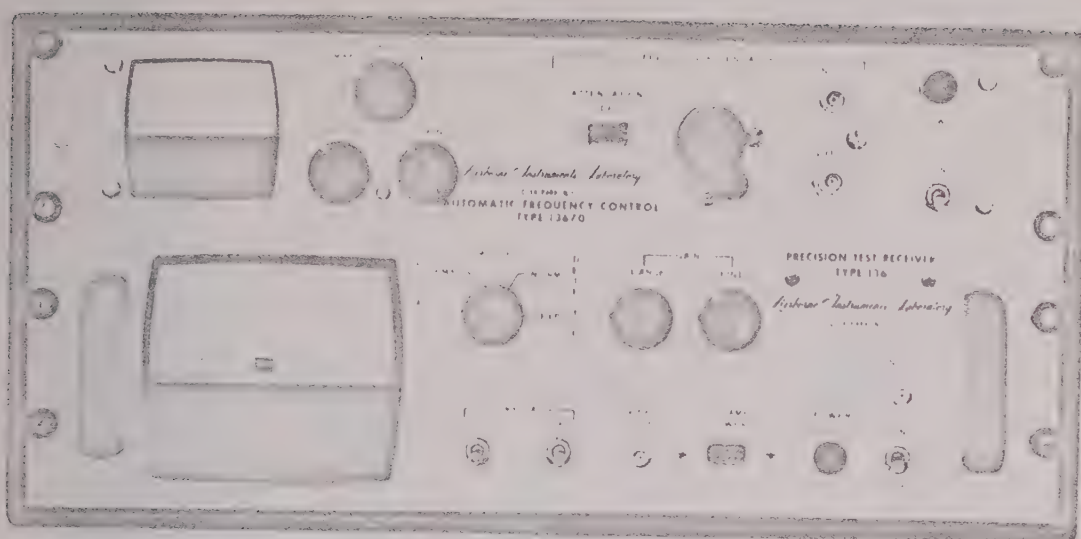


FIGURE 2. TYPE 136 PRECISION TEST RECEIVER, P/N 13620 (30 MHz)

Accessory items (Figure 3) are available for use with the Type 136 Receiver for a variety of applications. These include preamplifiers, pre-amplifier impedance adapters, mixers, and a frequency converter.

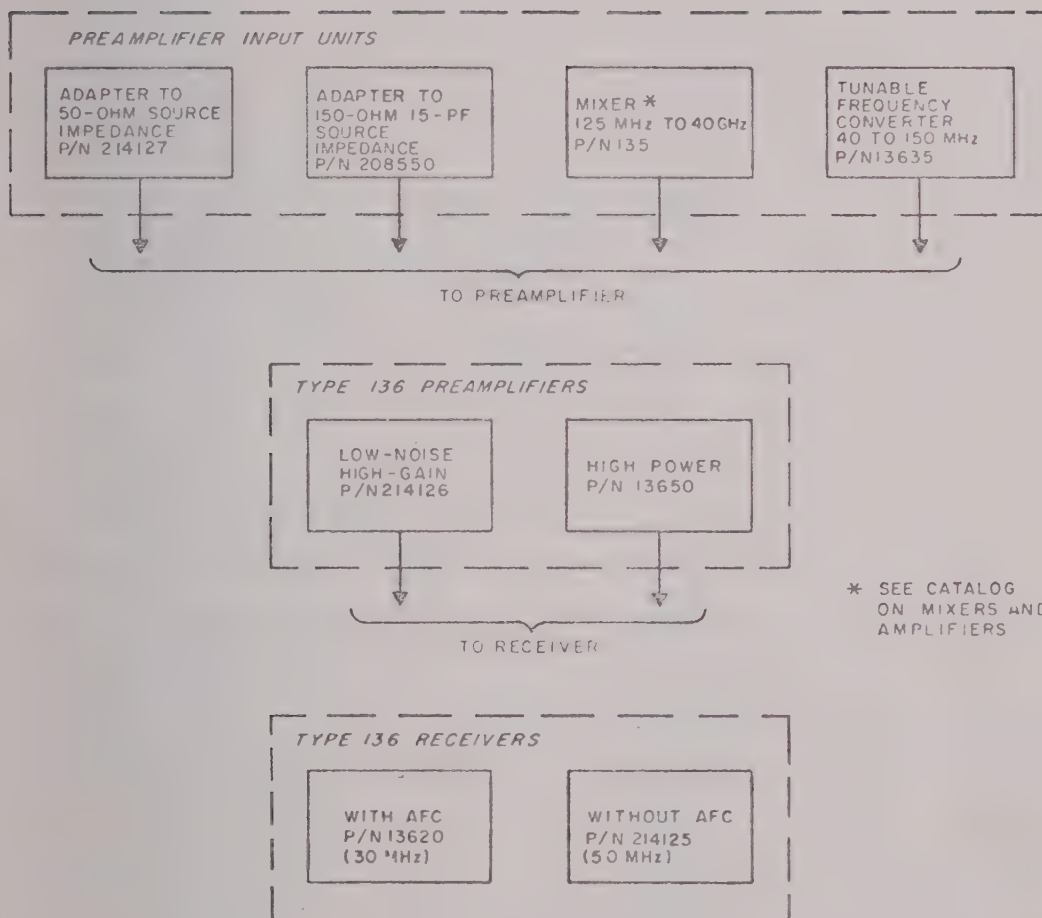


FIGURE 3. ACCESSORIES AND OPTIONS

SECTION 2. SPECIFICATIONS

2.1 RECEIVER, P/N 214125 (MODIFIED 13610)

Center frequency	50 MHz
3-db bandwidth	2.5 MHz
Noise figure	8.5 db (max)
Input impedance	50 ohms
Input SWR	1.5 (max)
Full-scale sensitivity (note 1)	-75 dbm
Overall IF and video gain	80 db
Gain control range	50 db
Attenuator:	
Center frequency	50 MHz
Minimum insertion loss	18 db Max
Maximum input power	1 watt
Input impedance (nom)	50 ohms
Output impedance (nom)	50 ohms
Phase shift	Constant over attenuation range
Attenuation range	0 to 100 db above minimum insertion loss.
Accuracy	± 0.05 db per 10 db of incremental change; ± 0.3 db max over 100-db range.
Shaft torque	✓ Less than 20 ounce-inches
Resolution	0.02 db/division
Measurement range:	
IF	100 db
Scale resolution	Normal: 0.1 db/division (note 2) Expanded: 0.01 db/division (note 3)

Video output (note 4)	0.5 volt (100-ohm load)
Rise and fall time	1.5 usec (max)
IF output	100 mv (50-ohm load)
Power required	115/230 VAC ± 10 percent, 50 to 400 Hz, 20 watts
Size (Figure 4)	19-13/16 by 9-7/8 by 17-3/4 inches
Weight	32 pounds

Notes:

1. Available signal power at Postamp input, which will cause the meter to read full-scale or greater, when the METER function switch is set to DETECTOR, NORM.
2. Change in input-signal level required for a change of a single division in meter indication when operating near full scale.
3. Sinusoidal signals only; resolution is 0.02 db per division when input consists of noise only.
4. At -75 dbm input signal.

2.2 RECEIVER WITH AUTOMATIC FREQUENCY CONTROL, P/N 13620 (30 MHz)

The following specifications relate to the AFC unit, P/N 13670. The specifications for the receiver and AFC unit together, P/N 13620, are the combined specifications of each individual unit (not part of P/N 214111).

Center frequency	30 MHz
Limiting level	40 mv rms
Linear range	± 1 MHz
Sensitivity:	
DC	25 volts/MHz
60 Hz	7.5 volts/MHz
Sensitivity control range	10:1
Maximum output	± 25 volts (1000-ohm load)
Insulation	3000 volts

Power requirement	115/230 VAC ± 10 percent, 50 to 400 Hz, 50 watts
Size	19-13/16 by 9-7/8 by 17-3/4 inches
Weight	18 pounds

2.3 LOW-NOISE PREAMPLIFIER, P/N 214126 (MODIFIED 13630)

Center frequency	50 MHz
IF noise figure	2.8 db (max)
Gain	40 db
Bandwidth	8 MHz
Linear output power	-10 dbm for 0.1-db compression
Power required	40 VDC at 27 ma or 15 VDC at 12 ma
Size (excluding mixers, adapters, and connectors)	$\times$ 5-1/4 by 3-1/4 by 1-1/2 inches
Weight	11 oz

2.4 HIGH-POWER PREAMPLIFIER, P/N 13650 (NOT PART OF P/N 214111)

Center frequency	30 MHz
IF noise figure	10 db
Gain	30 db
Bandwidth	2 MHz
Maximum output power	+28 dbm (50-ohm load)
Maximum linear output power	+15 dbm for 0.1-db compression
Power required	40 VDC at 135 ma
Size (excluding mixers, adapters, and connectors)	8-1/2 by 3-1/4 by 1-1/2 inches
Weight	16 oz

2.5 50-OHM ADAPTER, P/N 214127 (MODIFIED 208393)

Center frequency	50 MHz
Source impedance	50 ohms
Output impedance	150 ohms

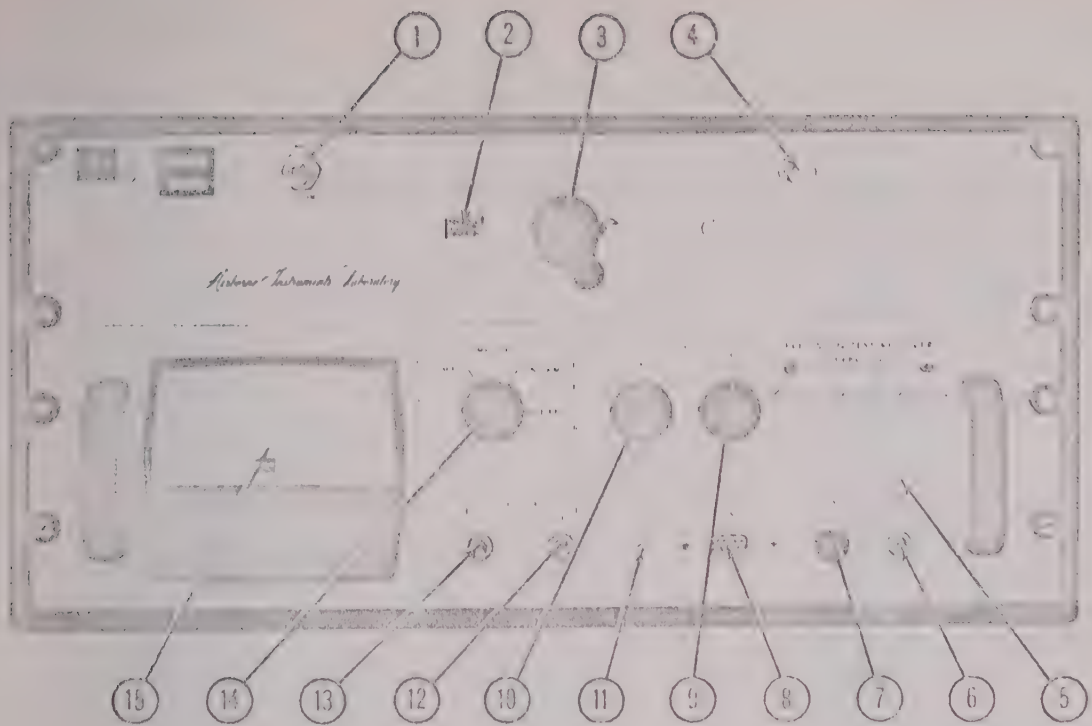


FIGURE 4. OUTLINE DRAWING OF P/N 214125 (50 MHz)
OR 13620 (30 MHz)

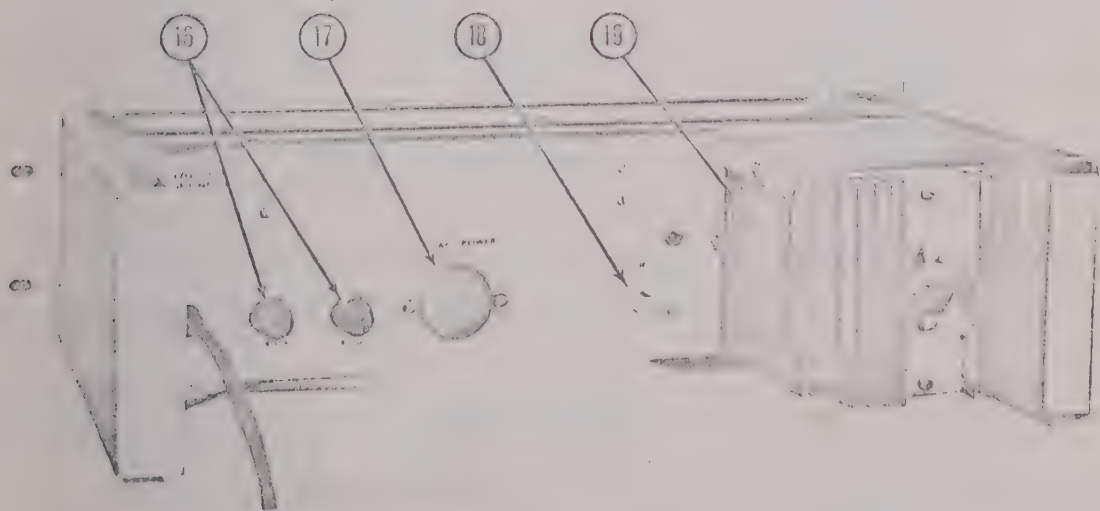
SECTION 3. OPERATING CONTROLS AND INDICATORS

Figure 5 shows the front- and rear-panel controls, indicators, and connectors for the 214125 (50 MHz).

<u>Reference Number</u>	<u>Nomenclature</u>	<u>Function</u>
1	INPUT 50 OHMS connector	Provides access to attenuator input
2	ATTENUATION DB indicator	Indicates attenuator setting
3	PRECISION ATTENUATOR knob	Controls attenuation setting continuously from 0 to 100 db
4	OUTPUT 50 OHMS connector	Provides access from attenuator output
5	INPUT connector	Provides access to postamplifier input
6	ON OFF switch	Controls primary power
7	POWER lamp	Lights when primary power is on
8	PREAMP POWER connector	Provides power for external preamplifier and access to crystal current meter
9	GAIN, FINE control	Provides vernier control of postamplifier gain
10	GAIN, COARSE control	Provides wide-range control of post-amplifier gain
11	VIDEO OUT connector	Provides access to video amplifier output
12	CRYSTAL +, - switch	Selects meter polarity for monitoring crystal current



A. FRONT PANEL



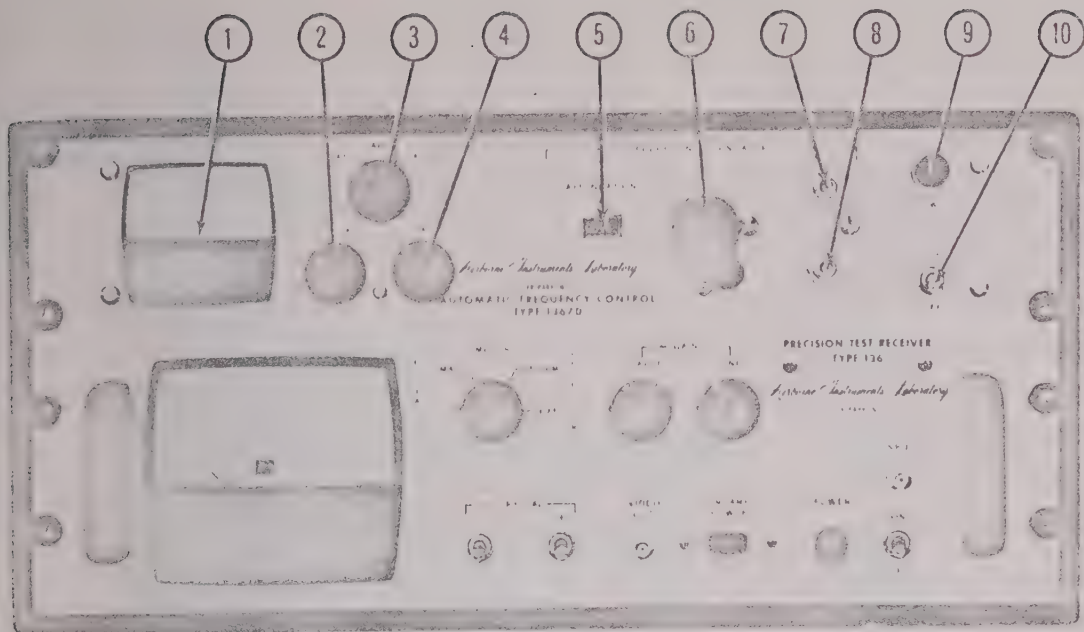
B. REAR PANEL

FIGURE 5. RECEIVER P/N 214125 (50 MHz), CONTROLS AND INDICATORS

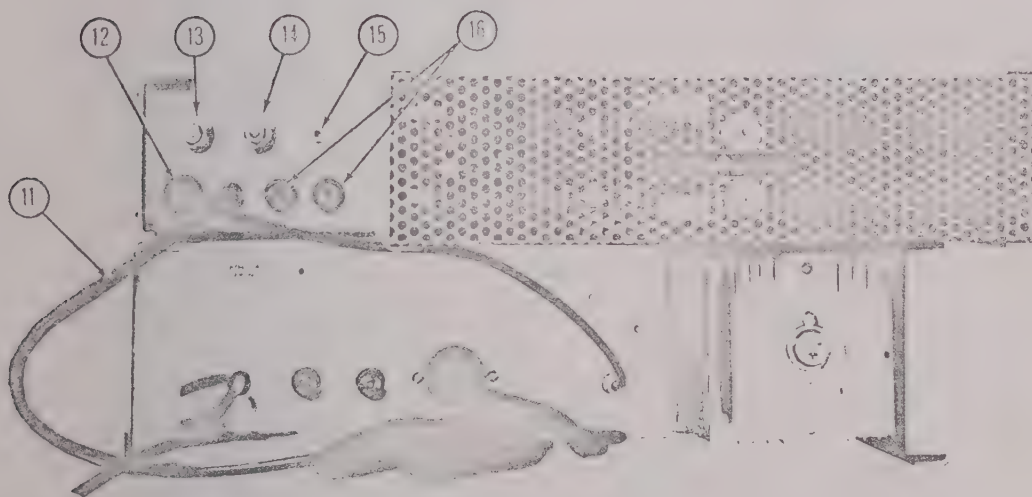
<u>Reference Number</u>	<u>Nomenclature</u>	<u>Function</u>
13	CRYSTAL 1, 2 switch	Selects crystal to be monitored
14	METER switch	Selects function of panel meter: CRYSTAL, 3MA - crystal current monitor DETECTOR, NORM - detector current normal sensitivity DETECTOR, EXP - detector current expanded scale
15	Meter	Indicates second detector and crystal currents
16	0.5A	Fuseholders, 0.5 Amp fuse
17	AC POWER	Power outlet for accessory
18	IF	IF output from post-amplifier
19	Power supply fuse	Access to power supply fuse

Figure 6 shows the front- and rear-panel controls, indicators, and connections for the 13670 (30 MHz) AFC unit.

<u>Reference Number</u>	<u>Nomenclature</u>	<u>Function</u>
1	Null indicator	Monitors discriminator output
2	ZERO ADJ control	Provides an adjustment of discriminator null frequency



A FRONT PANEL



B. REAR PANEL

FIGURE 6. RECEIVER P/N 13620 (30 MHz), CONTROLS AND INDICATORS

<u>Reference Number</u>	<u>Nomenclature</u>	<u>Function</u>
3	AFC switch	Selects manual (MAN) or automatic (AUTO) frequency control of local oscillator
4	GAIN control	Varies sensitivity of AFC unit
5	ATTENUATION DB indicator	Indicates attenuator setting
6	PRECISION ATTENUATOR knob	Controls attenuation setting
7	INPUT connector	Provides input to attenuator
8	OUTPUT connector	Provides output from attenuator
9	POWER lamp	Lights when primary power is on
10	ON OFF Switch	Controls primary power

SECTION 4. OPERATING INSTRUCTIONS

4.1. INTRODUCTION

The series-substitution method provides a simple, highly accurate method of measuring signal level changes or attenuation. It depends on the strict in-line substitution of attenuation for a changed signal level to reproduce an original reference level. The general procedure is as follows:

- a. A reference signal level is established at the input to the receiver system.
- b. The indicated signal level is noted by monitoring the postamplifier detector current. It is not necessary to know the absolute signal level.
- c. The input level is changed by: (1) inserting a device having an unknown attenuation into the system (Figure 7), or (2) changing the input signal level (either CW or noise).
- d. An accurate, continuously variable attenuator in series with the input is then varied until the detector current monitor returns to the original indication. The attenuator variation is then equal to the signal level change.

NOTE

All measurements described in this manual are made with the METER switch set to DETECTOR EXP. Extremely small signal-level changes (0.01 db per meter division for sinusoidal signals) can thus be resolved. If this precision is not required, the switch can be set to DETECTOR NORM. The system resolution will then be about 0.1 db for a single meter division when operating near full scale.

4.2. IF ATTENUATION MEASUREMENTS (50 MHz)

4.2.1. MEASUREMENT THEORY

The Type 136 Receiver can be used to make attenuation measurements of 100 db at 50 MHz. The arrangement of the measurement

equipment is shown in Figure 7. The high-power preamplifier is used to provide a high-level input signal. When operated with an input signal of at least 1 mw, it will provide an output of approximately 28 dbm. Under these conditions the output stage of the preamplifier saturates and thereby improves the amplitude stability of the signal source.

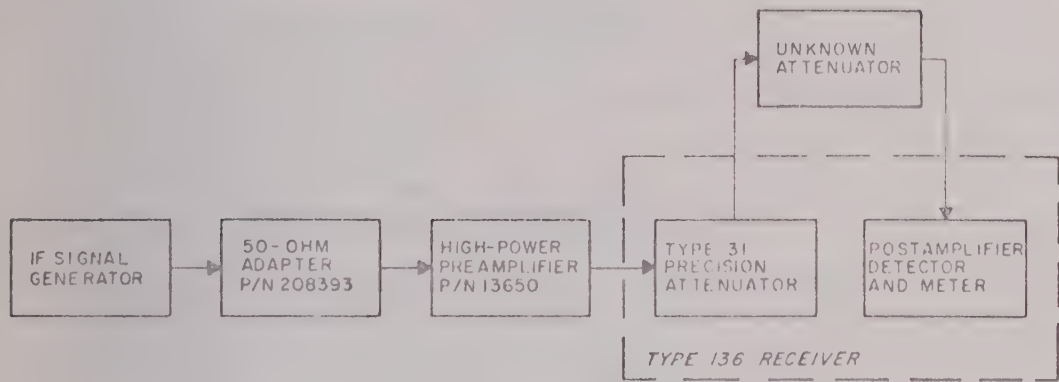


FIGURE 7. IF ATTENUATION MEASUREMENT SETUP

An alternate arrangement of this equipment which can be used to advantage in certain measurements is shown in Figure 8. The high-power preamplifier is not used, and the attenuation measurement range is limited by the power available from the signal generator. With an available power of 0 dbm, the attenuation measurement range is about 85 db.

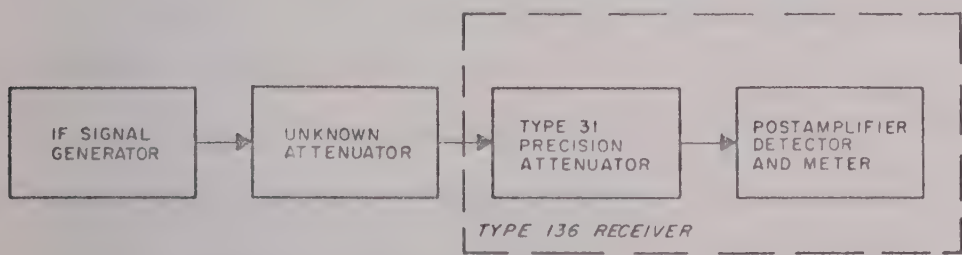


FIGURE 8. SIMPLIFIED IF ATTENUATION MEASUREMENT/SETUP

Typically, a measurement is made as follows: The precision attenuator is set to a convenient reference (0 db), and the output level of

the signal generator is set to 0 dbm. After the receiver gain is adjusted to obtain a convenient reference reading on the meter, the unknown is removed and the precision attenuator is connected directly to the signal source. The precision attenuator is increased until the meter returns to the original reference indication. The unknown attenuation is read directly (in db) on the precision attenuator indicator.

4.2.2. MEASUREMENT PROCEDURE

- a. Set up equipment as shown in either Figure 7 or 8, depending on the conditions discussed above.
- b. Set the PRECISION ATTENUATOR to 0 db.
- c. Set the signal-generator output level to 0 dbm.
- d. Set the METER switch to DETECTOR NORM.
- e. Adjust the GAIN controls for a full-scale indication on the receiver front-panel meter. If necessary, readjust the signal-generator output level.
- f. Set the METER switch to DETECTOR EXP.
- g. Adjust the FINE GAIN control for a convenient reference level indication on the meter.
- h. Remove the unknown attenuator.
- i. Increase the PRECISION ATTENUATOR setting until the meter returns to the reference indication that was set in step g.
- j. Read the unknown attenuation on the ATTENUATION DB readout.

4.3. RF ATTENUATION MEASUREMENTS

4.3.1. MEASUREMENT THEORY

The measurement of RF attenuation requires the use of a mixer to convert the signal to the 50-MHz center frequency of the receiver. This can be conveniently performed by mating either one of the Type 136

preamplifiers to one of the AIL Type 135 mixers (Appendix C) or by attaching an impedance adapter to one of the Type 136 preamplifiers and using any standard mixer having a single-ended IF output of the proper impedance. Figure 9 shows the general setup for measuring RF attenuation.

The measurement procedure is basically identical with that for IF attenuation measurement. As shown in Figure 9, the unknown is inserted between the signal source and the input of the mixer. The precision attenuator is between the preamplifier output and the postamplifier IF input.

This arrangement sets a further limitation on the measurement range and accuracy. The mixer-preamplifier combination must remain absolutely linear over the full variation of input-signal level. In this measurement the linear dynamic range of the mixer-preamplifier combination determines the attenuation measurement range.

The linear dynamic range of any receiver is limited at low signal levels by the system noise level. Using a Type 135 Mixer mated to a Type 136 High-Power Preamplifier (P/N 13650, 30 MHz) results in a system noise level that limits the minimum useful signal level to approximately -80 dbm.

The upper limit of the linear range of the system is determined by the signal-handling capability of the mixer. For a maximum error of 0.2 db due to this limitation, the input signal level must not exceed a level of 8 db below the power delivered to the crystals by the local oscillator.

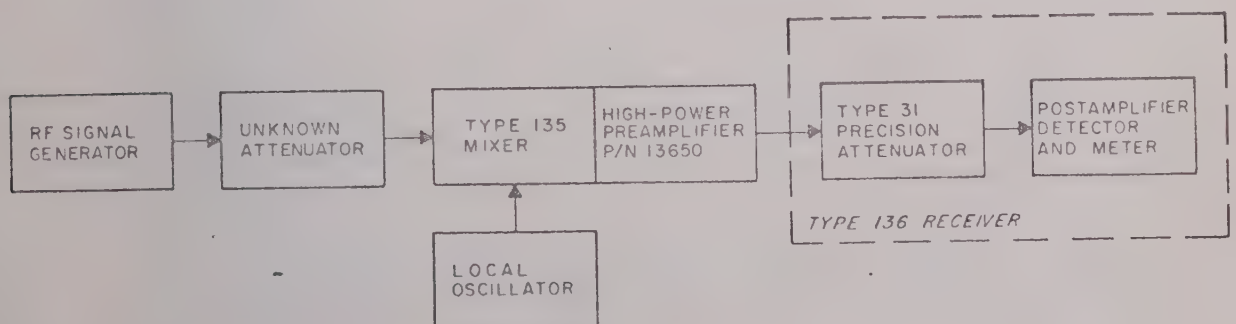


FIGURE 9. RF ATTENUATION MEASUREMENT SETUP

Noise matching and conversion efficiency considerations generally require an input to the crystals of a balanced mixer of about 2 mw. The corresponding upper limit of the linear signal range is approximately -5 dbm.

It can be seen that, if maximum accuracy is to be maintained over the full measurement range of the instrument, the input signal level to the mixer must remain within the limit of -80 to -5 dbm. This allows a maximum single-step measurement of 75 db. Figure 10 shows the error in a typical RF attenuation measurement setup. This characteristic is shown as a guide only. To obtain the maximum accuracy in any system, the user should measure this characteristic of his own equipment (Appendix A).

When it is desired to make power-level measurements below -80 dbm, the range of the measurement setup can be extended by using the low-noise preamplifier. This preamplifier, when used with a Type 135 mixer, is useful over the RF signal range from -55 to -90 dbm.

A method that can be used to increase the RF attenuation measurement range is partial RF substitution. The procedure is described under paragraph 4.3.3. Basically, the difference between this method and the

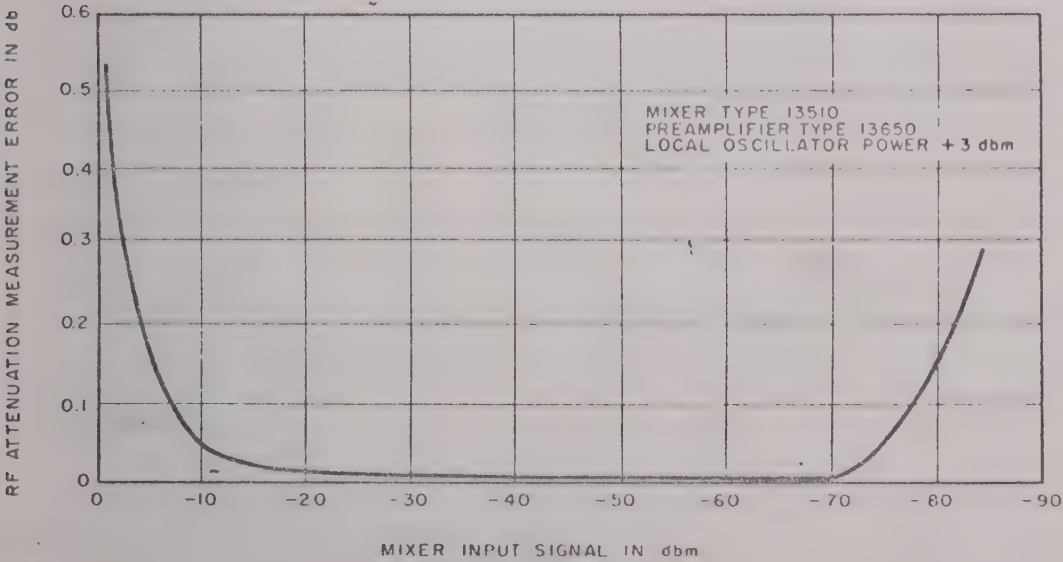


FIGURE 10. RF ATTENUATION MEASUREMENT ERROR

single-step method described above is that a fixed RF attenuator of known insertion loss is inserted in place of the unknown attenuator for the second reading. This attenuator permits the use of a higher input signal from the signal generator, and the available increase in attenuation measurement range is limited to the increase in available power above the limit of -5 dbm described above.

4.3.2. MEASUREMENT PROCEDURE (SINGLE STEP)

- a. Set up the equipment as shown in Figure 9.
- b. Set the AFC switch to MAN (Type 13620, 30 MHz receivers only).
- c. Set the signal generator to the desired operating frequency.
- d. Adjust the signal-generator output level so that the mixer input is about -60 dbm.
- e. Set the PRECISION ATTENUATOR to zero.
- f. Set the local-oscillator frequency 50 MHz higher than the signal-generator frequency.
- g. Set the METER switch to CRYSTAL 3 MA.
- h. Adjust the local-oscillator output for the rated crystal current (1 to 2 ma for the Type 135 mixers) as indicated by the front-panel meter. It may be necessary to operate the CRYSTAL 1,2 and +, - switches to obtain up-scale readings.
- i. Set the METER switch to DETECTOR NORM.
- j. Carefully adjust the local-oscillator frequency for a peak indication on the meter. Adjust the GAIN controls, if necessary, to maintain an on-scale indication.
- k. Set the signal generator output level in accordance with the criteria established in paragraph 4.3.1.
- l. Adjust the GAIN controls for a full-scale indication on the meter.

m. Set the METER switch to DETECTOR EXP.

n. Adjust the FINE GAIN control for a convenient reference setting on the meter.

o. Remove the unknown attenuator, and connect the signal-generator output directly to the mixer input.

p. Adjust the PRECISION ATTENUATOR until the detector meter is at the reference set in step n.

q. Read the unknown attenuation directly from the ATTENUATION DB readout.

4.3.3. MEASUREMENT PROCEDURE (PARTIAL RF SUBSTITUTION)

a. Set up the equipment as shown in Figure 9.

b. Set the AFC switch to MAN (Type 13620, 30 MHz receivers only).

c. Set the signal generator to the desired operating frequency.

d. Adjust the signal-generator output level so that the mixer input is about -60 dbm.

e. Set the PRECISION ATTENUATOR to zero.

f. Set the local-oscillator frequency 50 MHz higher than the signal-generator frequency.

g. Set the METER switch to CRYSTAL 3 MA.

h. Adjust the local-oscillator output for the rated crystal current (1 to 2 ma for the Type 135 mixers) as indicated by the front-panel meter. It may be necessary to operate the CRYSTAL 1,2 and +, - switches to obtain up-scale readings.

i. Set the METER switch to DETECTOR NORM.

j. Carefully adjust the local-oscillator frequency for a peak indication on the meter. Adjust the GAIN controls, if necessary, to maintain an on-scale indication.

k. Insert a fixed, calibrated RF attenuator in place of the unknown attenuator.

l. Set the signal generator output level to maintain the signal level at the input to the mixer within the limits described in paragraph 4.3.1, with either the calibrated attenuator or the unknown attenuator in place.

m. Insert the unknown attenuator in place of the calibrated attenuator.

n. Adjust the GAIN controls for a full-scale indication on the meter.

o. Set the METER switch to DETECTOR EXP.

p. Adjust the FINE GAIN control for a convenient reference setting on the meter.

q. Replace the unknown attenuator with the calibrated attenuator.

r. Adjust the PRECISION ATTENUATOR until the detector meter is at the reference set in step p.

s. Read the ATTENUATION DB readout. The unknown attenuator is equal to the sum of this reading and the attenuation (db) of the calibrated attenuator.

4.4. RF ATTENUATION MEASUREMENTS USING AUTOMATIC FREQUENCY CONTROL

4.4.1. MEASUREMENT THEORY

The accuracy of attenuation measurements made by the series-substitution method depends directly on the gain stability of the system. If the receiver gain changes during the measurement procedure, the measurement accuracy will be in error by the amount of the gain change.

One possible cause of a gain change during an RF measurement is a change in the operating frequency, due, for example, to signal-generator

frequency drift. The AFC unit can substantially reduce the error caused by frequency drift in either the local oscillator or the signal source.

The use of the Type 136 AFC unit requires a local oscillator whose frequency can be controlled by an externally applied voltage. This is generally accomplished by klystron repeller voltage control or the use of solid-state voltage-tunable oscillators. The output terminals of the AFC are insulated for 3000 volts above ground.

This allows the control voltage to be inserted in series with a klystron repeller voltage power supply. Several signal generators presently available incorporate front-panel connections for external voltage control of frequency. Typical examples are the Polarad line of modular signal sources and the Hewlett-Packard Model 8600 series of signal generators.

In some cases it may be more convenient to use automatic frequency control of the signal generator instead of the local oscillator. In either case the operating procedure is the same.

4.4.2. MEASUREMENT PROCEDURE

- a. Set up the equipment as shown in Figure 11.
- b. Follow the adjustment procedure of paragraph 4.3.2, steps (a) through (j).

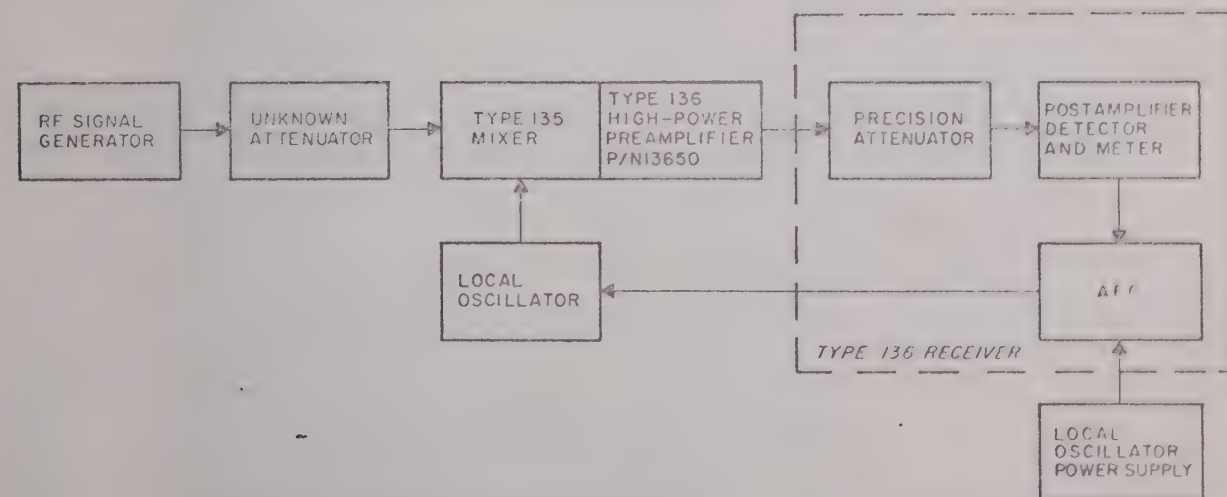


FIGURE 11. SETUP FOR MEASURING RF ATTENUATION WITH AFC

c. After completing step (j), set the AFC GAIN controls to maximum (fully clockwise).

d. If necessary, adjust the AFC ZERO ADJ control for zero on the AFC tuning meter.

e. Set the AFC mode switch to AUTO. If the detector meter goes off scale or becomes unstable, slowly reduce the setting of the AFC GAIN control (counter-clockwise) until a stable on scale reading is obtained.

f. Repeat steps (d) and (e). If the system fails to lock, the phasing of the AFC correction voltage may be incorrect. It will then be necessary to retune the local oscillator 50 MHz below the signal, or reverse the AFC connections at the rear of the unit.

g. Continue the measurement procedure following steps (k) through (q) of paragraph 4.3.2.

4.5. GAIN MEASUREMENTS

Gain measurements at IF or RF are made in the same manner as attenuation measurements. For convenience the reference indication is set and noted before inserting the unknown into the circuit. All precautions regarding signal levels should also be observed in these measurements.

4.6. ACCURACY OF ATTENUATION MEASUREMENTS

The procedures described above for the measurement of attenuation illustrate the manner in which the equipment is arranged and the sequence of operation. Certain techniques common to each of these measurements should be adopted to avoid errors resulting from impedance mismatch, nonlinearity of vital components, and other imperfections in the test equipment. Sufficient information is contained in Appendix A to enable the operator to detect these errors and to take corrective action.

4.7. THEORY OF NOISE-FIGURE MEASUREMENT

The Type 136 Receiver can be used to make very accurate noise-figure measurements by means of the manual Y-factor method. In this

measurement the change in the noise output level of the device under test is noted when a known change is made in the noise power available from the input termination. The desired change in available noise power (or effective source temperature) is accomplished by means of a variety of noise generators. A complete list of suitable noise generators is contained in Appendix C. The formulas used in calculating the measured noise figure and their derivations are contained in Appendix B.

4.8. PRELIMINARY ADJUSTMENTS FOR NOISE FIGURE MEASUREMENTS

4.8.1. RF AMPLIFIER

For purposes of this test procedure any amplifier having the same input and output frequencies is defined as an RF amplifier. The arrangement of the test equipment required for noise-figure measurements is shown in Figure 12. The AIL series of mixers designated as Type 135 covers the frequency range from 125 MHz to 72 GHz. They are designed to be secured interchangeably to the front end of the amplifier. The proper mixer for the desired frequency range can be selected from the list in Appendix C. In addition, an amplifier operating at 50 MHz can be tested by using the 50-ohm adapter (AIL Part No. 214127, 50 MHz) in place of a mixer.

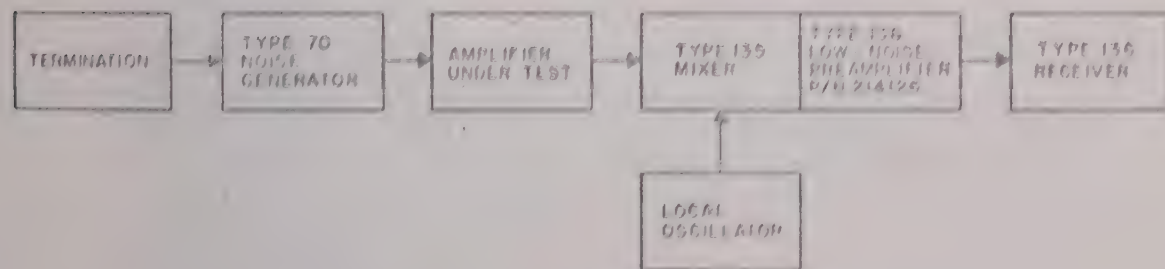


FIGURE 12. SETUP FOR MEASURING NOISE FIGURE OF RF AMPLIFIER

The initial adjustments for this type of measurement are:

- a. Set the AFC switch to MAN (Type 13620 Receivers only).
- b. Set the local-oscillator frequency 50 MHz above or below the desired operating frequency (the local oscillator can be adjusted for maximum detector current).
- c. Set the METER switch to CRYSTAL 3 MA.
- d. Adjust the local-oscillator output level for rated crystal current on both crystals. It will be necessary to operate the CRYSTAL selector (1 or 2) and polarity (- or +) switches to obtain an up-scale reading and determine whether both crystals are operating.
- e. Set the METER switch to DETECTOR NORM.
- f. Set the PRECISION ATTENUATOR to zero.

4.8.2. SUPERHETERODYNE RECEIVER

A superheterodyne receiver is an amplifier in which a part of the total gain is accomplished at an intermediate frequency that is different from the signal input frequency. When an output at this intermediate frequency is available from the receiver, a measurement of the noise figure of the receiver can be made using the test equipment shown in Figure 13.

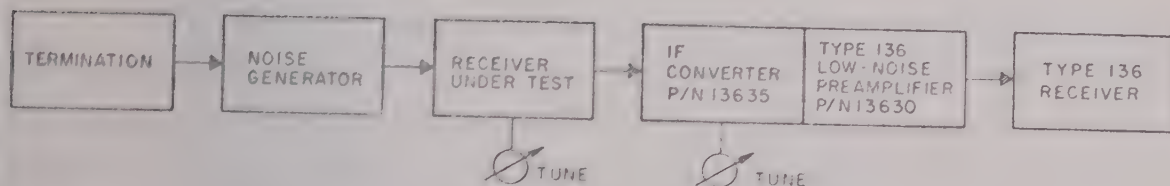


FIGURE 13. NOISE-FIGURE MEASUREMENT SETUP FOR SUPERHETERODYNE RECEIVER

The AIL frequency converter (P/N 13635) covers the range from 10 to 150 MHz. When the IF of the receiver under test is 30 MHz, the

converter is replaced by a simple impedance-matching device (P/N 208393) that provides a 50-ohm input impedance for the preamplifier. Both the converter and the preamplifier can be omitted if the receiver under test has sufficient gain (45 db minimum) from the RF input to the 30 MHz output.

The initial adjustments for this measurement are:

- a. Set the AFC switch to MAN (Type 13620, 30 MHz Receiver only).
- b. Tune the receiver to the desired operating frequency.
- c. Tune the IF converter to the output frequency of the receiver under test; adjust for maximum output.
- d. Set the METER function switch to NORM.
- e. Set the PRECISION ATTENUATOR to zero.

4.8.3. MIXER

A mixer has an output at an intermediate frequency that differs from the signal input frequency. However, the usual microwave mixer has an overall power loss. Noise-figure measurement of such a device must take into account the noise figure of the amplifier following the mixer. Furthermore, this amplifier must be designed to operate from the source impedance presented by the mixer or, at least, its noise figure must be known when operating from this particular source impedance.

The 150-ohm impedance adapter is suitable for use with most mixers employing two microwave diodes. The manner in which these impedance and other factors are taken into account in the measurement of noise figure is covered in Appendix B. The general arrangement of the test equipment is shown in Figure 14.

The following initial adjustments should be made:

- a. Set the AFC switch to MAN (Type 13620, 30 MHz Receivers only).
- b. Set the local-oscillator frequency 30 MHz above or below the desired operating frequency (the local oscillator can be adjusted for maximum detector current).

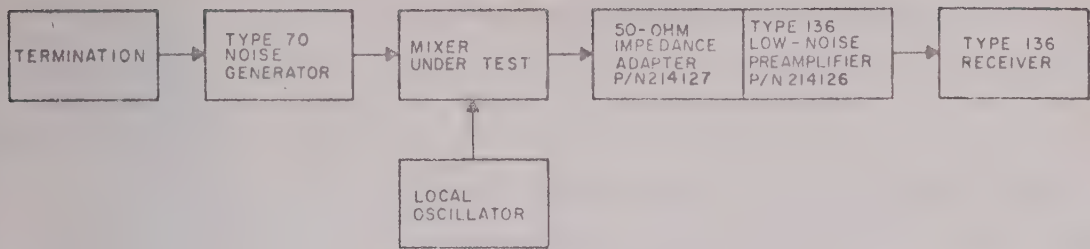


FIGURE 14. SETUP FOR NOISE-FIGURE MEASUREMENT OF A MIXER

c. Adjust the local-oscillator output level in accordance with the requirements of the mixer. In certain mixers having provisions for monitoring crystal current through the IF output connection, this current can be measured on the receiver panel meter by setting the METER function switch to CRYSTAL 3 MA. It will be necessary to select the proper positions of the CRYSTAL selector (1 or 2) and polarity (- or +) switches to obtain a meter reading.

d. Set the METER function switch to NORM.

e. Set the PRECISION ATTENUATOR to zero.

4.9. NOISE-FIGURE MEASUREMENT PROCEDURES

The procedure for measuring noise figure will vary slightly, depending on the type of noise generator used: temperature-limited diode, gas-discharge, or hot-cold standard noise generator.

4.9.1. TEMPERATURE-LIMITED DIODE (Y-FACTOR METHOD).

A thermionic diode, operated in the temperature-limited region of its V-I characteristic and properly terminated, makes an accurate noise generator in the IF-UHF region. The AIL Type 07006 is such a device. The termination and coupling network are internal to the noise source. A noise-diode power supply, such as the AIL Type 07112, is also required for this measurement. A power supply of this type is also an integral part of the Type 74A Automatic Noise Figure Indicator. The measurement procedure is as follows:

- a. Set up the equipment in accordance with paragraphs 4.8.1, 4.8.2, or 4.8.3, and perform whatever initial adjustments are required (local-oscillator settings, etc.).
- b. Connect the noise-generator output to the input of the system under test, and connect the noise-generator power cable to its power supply.
- c. Check that the METER switch is set to DETECTOR NORM and the PRECISION ATTENUATOR set to zero db.
- d. With the noise-diode power supply turned off, adjust the GAIN controls for a full-scale reading on the meter.
- e. Set the METER switch to DETECTOR EXP.
- f. Adjust the GAIN controls for a convenient reference reading.
- g. Energize the noise-diode power supply.
- h. Place the power supply RANGE switch to the 0-16 db position.
- i. Adjust the diode current for a reading of 15.3 db on the power supply meter (33.8 ma, if the power supply meter reads diode plate current directly).
- j. Increase the setting of the PRECISION ATTENUATOR until the receiver meter returns to the reference setting of step f.
- k. The new attenuator reading is the Y factor.
- l. Using the 15.3-db curve in Figure 15, read the system noise figure corresponding to the measured Y factor, or use the AIL Noise Figure Slide Rule.

4.9.2. TEMPERATURE-LIMITED DIODE (3-DB METHOD)

The ease with which the noise output of the Type 7006 Noise Diode can be varied provides a second, convenient method of measuring noise figure. This is called the 3-db or Constant Y-Factor Method.

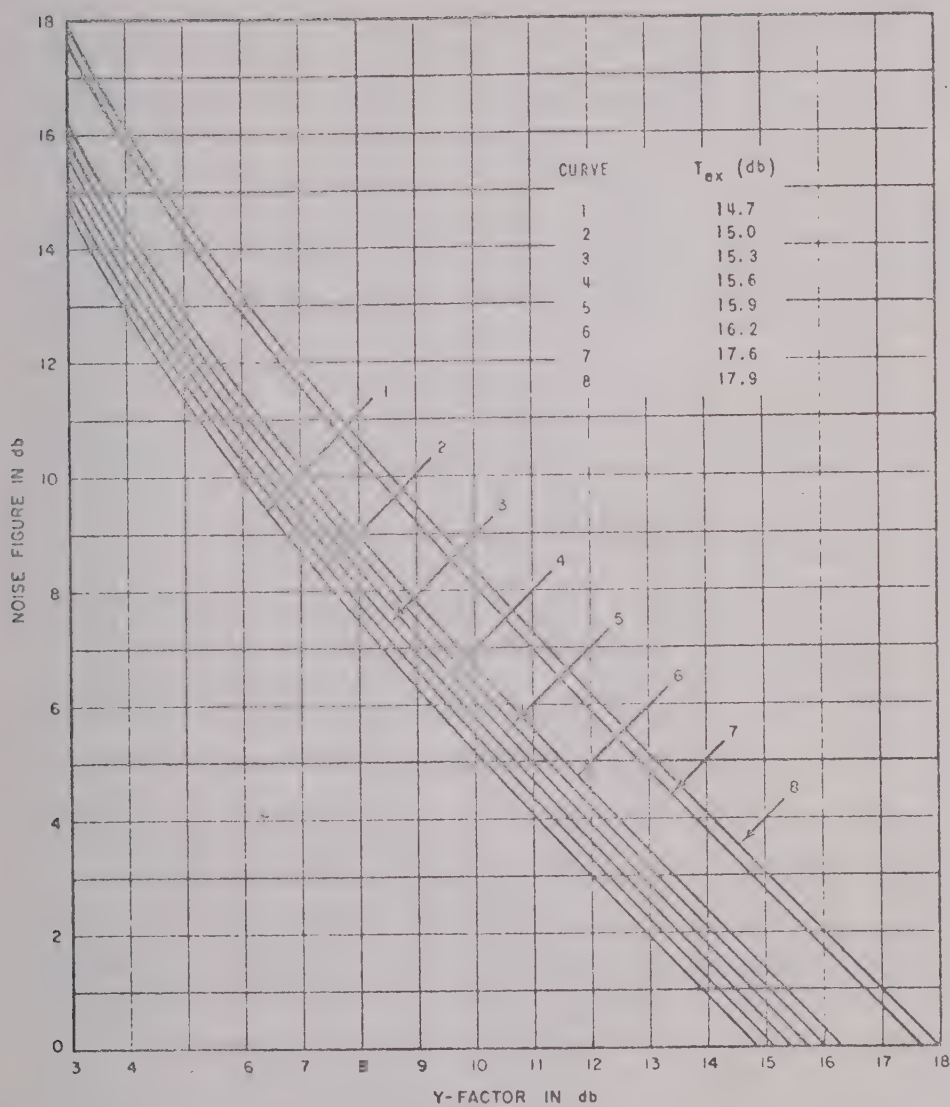


FIGURE 15. NOISE FIGURE VERSUS Y FACTOR FOR VARIOUS DISCHARGE GENERATORS

- a. Set up the equipment in accordance with paragraphs 4.8.1, 4.8.2, or 4.8.3, and perform whatever initial adjustments are required (local-oscillator settings, etc.).
- b. Connect the noise-generator output to the input of the system under test, and connect the noise-generator power cable to its power supply.
- c. Check that the METER switch is set to DETECTOR NORM and the PRECISION ATTENUATOR set to zero db.
- d. With the noise-diode power supply turned off, adjust the GAIN controls for a full-scale reading on the meter.
- e. Set the METER switch to DETECTOR EXP.
- f. Adjust the GAIN controls for a convenient reference reading.
- g. Readjust the PRECISION ATTENUATOR for a reading of exactly 3 db.
- h. Energize the noise-diode power supply.

Adjust the noise-diode current, until the receiver front-panel meter again indicates the reference level set in step f.

- i. If the Type 07112 Noise Diode Power Supply is used, read the system noise figure directly from its front-panel meter.
- j. Alternatively, if the noise-diode plate current is read directly (as when the Type 74A Automatic Noise Figure Indicator is used as a power supply), the system noise figure (in db) can be calculated from the following expression:

$$F = 10 \log 20 IR$$

where

I = noise diode DC plate current in amperes,

R = terminating resistance in ohms.

In the Type 7006 Noise Diode, R is equal to 50 ohms. Consequently,

$$F = 10 \log I \text{ (ma)}.$$

4.9.3 GAS-DISCHARGE NOISE GENERATOR

Gas-discharge noise generators are generally used above 200 MHz. AIL Type 70 Noise Generators (see Appendix C) cover the range of 200 MHz to 40 GHz. Two coaxial types (7010 and 7012) operate from 200 MHz to 5 GHz, and a series of waveguide types are used to cover the range from 2.6 to 40 GHz.

Gas-discharge noise generators require a special power supply that provides an ignition pulse many times higher than the operating potential as well as the sustaining voltage and current. The AIL Type 7111 Noise Generator Power Supply serves this purpose in addition to providing noise generator current monitoring and control. The Type 74A Automatic Noise Figure Indicator also contains a suitable gas-discharge noise-generator power supply.

Gas-discharge generators are provided without terminations; however, internally mounted terminations (listed in Appendix C) are available from AIL for the waveguide units. Standard commercial coaxial RF terminations are usually suitable for the coaxial generators.

The Y-factor method is the most popular means of making noise-figure measurements with gas-discharge noise generators. The procedure described below is essentially the same as that used with noise diodes (paragraph 4.9.1). The correct operating current is listed in the handbook of operating instructions for the particular generator.

- a. Connect the noise-generator output to the input of the system under test. Connect a termination to the opposite end, and connect the power cables from the power supply. Make whatever initial adjustments are required (local-oscillator settings, etc.).
- b. Check that the PRECISION ATTENUATOR is set to zero db.
- c. Set the METER switch to DETECTOR NORM.
- d. Adjust the GAIN controls for a full-scale meter indication.
- e. Set the METER switch to DETECTOR EXP.
- f. Adjust the GAIN controls for a convenient reference reading.
- g. Ignite the noise lamp by operating the noise-generator power supply. Set the current adjust control for the proper operating current (refer to the noise-generator handbook).

- h. Readjust the PRECISION ATTENUATOR until the meter returns to the reference set in step f.
- i. The new setting of the PRECISION ATTENUATOR is the Y factor.
- j. Refer to Figure 15. Using the T_{ex} curve closest to that given in the noise-generator handbook, read the system noise figure corresponding to the measured Y factor.

4.9.4 HOT-COLD STANDARD NOISE GENERATORS

The AIL Type 07002 and 07004 Hot-Cold Standard Noise Generators cover frequencies from DC to 2 GHz and DC to 6 GHz, respectively. These are the most accurate noise generators commercially available. No external power supplies or terminations are required because these instruments operate by providing true thermal noise at two accurately known temperatures. The procedure for measuring noise figure using these instruments is the Y-factor method.

- a. Refer to the handbook of the 07002 or 07004 for their respective filling and stabilization procedures.
- b. Connect the cold output of the noise generator to the system input, and make any initial adjustments (local-oscillator settings, etc.) required by the system under test. Check that the PRECISION ATTENUATOR is set to zero db.
- c. Set the METER switch to DETECTOR NORM.
- d. Adjust the GAIN controls for a full-scale meter indication.
- e. Set the METER switch to DETECTOR EXP.
- f. Adjust the GAIN controls for a convenient reference reading.
- g. Connect the system input to the hot termination.
- h. Readjust the PRECISION ATTENUATOR until the meter returns to the reference set in step f.

- i. The new setting of the PRECISION ATTENUATOR is the Y factor.
- j. Refer to Figure 16, and read the system noise figure corresponding to the measured Y factor.

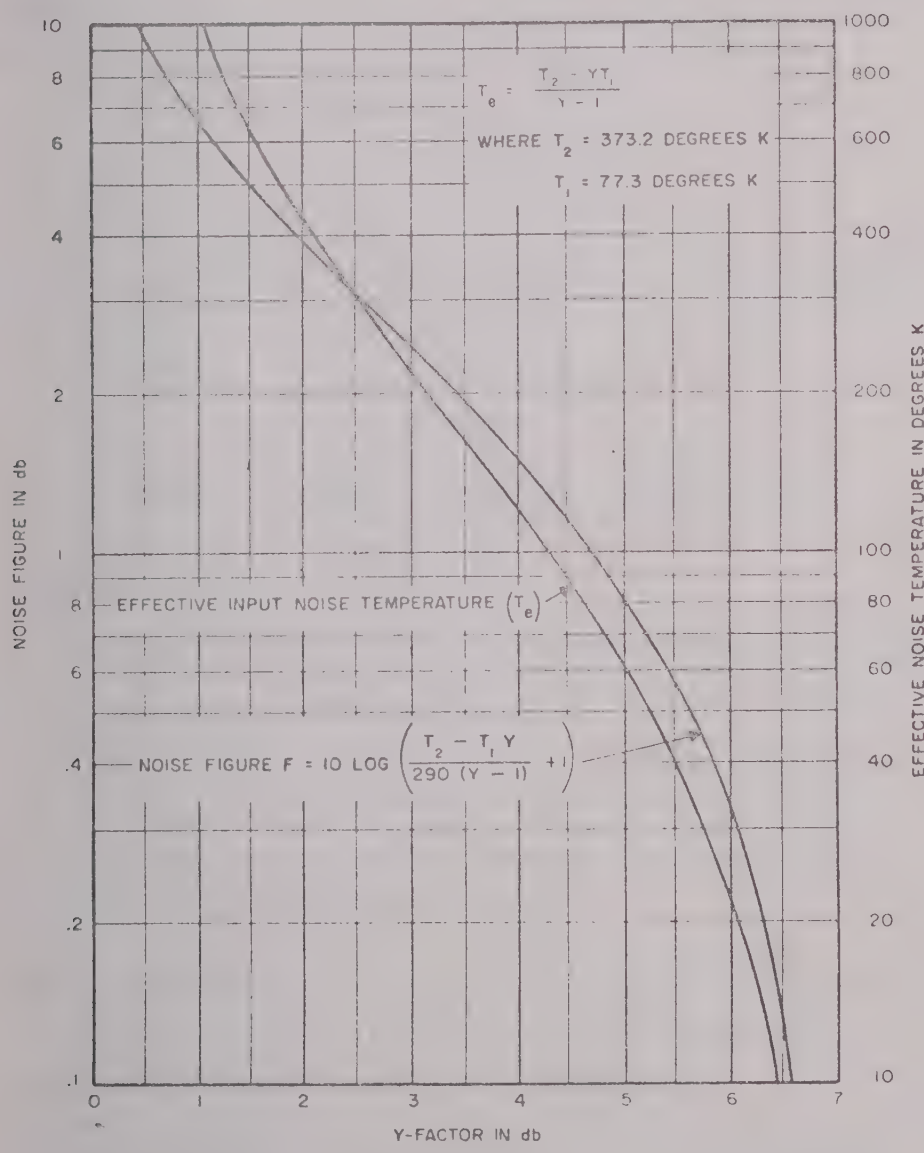


FIGURE 16. NOISE FIGURE AND EFFECTIVE INPUT-NOISE TEMPERATURE VERSUS Y FACTOR FOR TERMINATION TEMPERATURES OF 77.3 AND 373.2°K.

SECTION 5. THEORY OF OPERATION

5. 1. GENERAL

The Type 136 Receiver is essentially a highly stable, 30-MHz amplifier preceded by a precision 1F attenuator and followed by a detector and display circuit. Figure 17 is a block diagram of the basic receiver showing the arrangement of the major components. This section describes the circuit theory of the various component parts of the receiver.

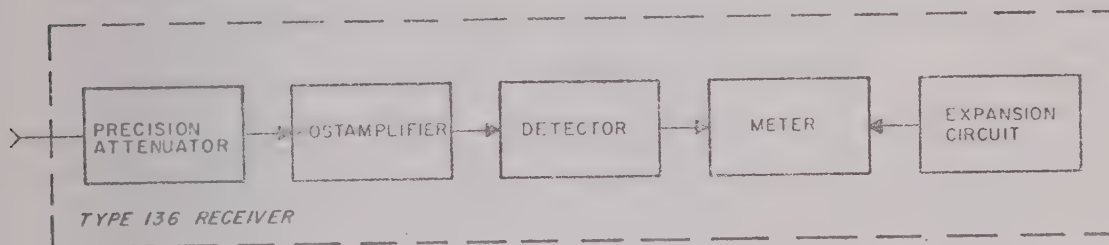


FIGURE 17. SIMPLIFIED BLOCK DIAGRAM OF BASIC TYPE 136 RECEIVER

5. 2. PRECISION ATTENUATOR

The precision attenuator used in the Type 136 Receiver consists of a cylindrical cavity whose diameter is such that it forms a waveguide well below cutoff at the 50-MHz operating frequency. The launch coil is part of a piston that travels in an axial direction in the waveguide. This coil is tuned by a series capacitor, and the tuning elements are loaded with a series resistor to provide the proper input impedance.

The receiving coil is fixed at the opposite end of the waveguide. This coil is also tuned with a series capacitor and loaded with a series resistor, thus providing the 50-ohm output impedance.

True wave propagation does not exist in a waveguide below cutoff. The fields are exponentially attenuated down the length of the waveguide with a rate of attenuation that is determined by the transmission mode. For any

single mode, the attenuation (in db) is a linear function of the length of the waveguide.

The effective length of the waveguide can be changed by varying the separation between the coils. Thus, for a particular mode, the attenuation, (in db) can be read directly from the linear counter dials.

The primary transmission mode of the precision attenuator used in the Type 136 Receiver is a TE₁₁ mode. This is the lowest mode that will propagate in a circular waveguide; it also has the lowest attenuation constant. If other modes are generated and propagate down the waveguide, they are attenuated faster than this primary mode of transmission.

If the separation between the two coils were reduced to where coupling to the spurious modes is significant, the linearity of the attenuation (in db) versus distance characteristic of the attenuator would be affected. Consequently, in a practical device of this sort, it is necessary to provide a minimum separation between the radiating and receiving coils and, thus, preserve the accuracy of the attenuator.

This separation naturally introduces a fixed attenuation between the input and output of the precision attenuator which is called the minimum insertion loss of the device. Careful design of the radiating and receiving coils and selection of an optimum waveguide diameter allow such close coupling, that the precision attenuator in a Type 136 Receiver exhibits a minimum insertion loss of less than 18 db. This minimum loss is set such that there is no observable degradation in the linearity or accuracy of the attenuator over the first 10 db of incremental attenuation.

5.3. POSTAMPLIFIER

The postamplifier (Figure 18) is a subassembly of the basic Type 136 Receiver. It consists of five stages of 50-MHz amplification, a detector, an emitter-follower IF output stage, and an emitter-follower video output stage. The unit is synchronously tuned to the center frequency of 50-MHz and has a bandwidth of 1 MHz. The gain is about 100 db from the IF input

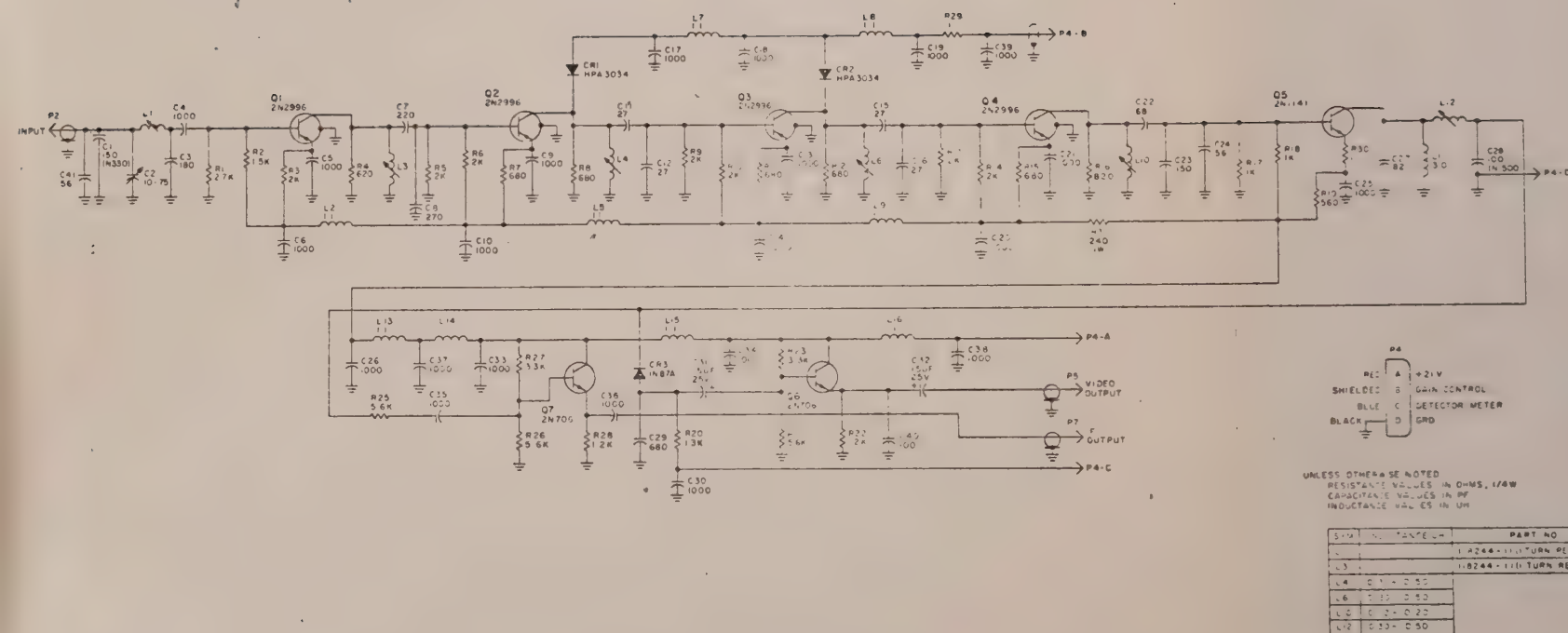


FIGURE 18. POSTAMPLIFIER (P/N 214128, 50 MHz)
SCHEMATIC DIAGRAM

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5. 3. 4. IF OUTPUT STAGE

Transistor Q7 is an emitter follower that provides a 50-MHz output generally used to drive the limiter-discriminator of the AFC unit. There is no tuning on this stage, and the 2N706 used will provide about 150 mv rms when loaded with 50 ohms.

5. 3. 5. DETECTOR

The postamplifier detector is a simple envelope detector consisting of CR3, a 1N87A germanium diode. Capacitor C29 is the detector filter capacitor, which is loaded by series resistor R20 and the display circuits.

5. 3. 6. VIDEO OUTPUT

A video output is available using a 2N706 transistor Q6, connected as an emitter follower. The rise time of the output pulse is limited by the bandwidth of the IF amplifier and does not exceed 1.5 usec.

5. 3. 7. GAIN CONTROL

Two methods of gain control are used in the Type 136 postamplifier. The major control is effected by means of variable loading on the collectors of transistors Q2 and Q3, two of the intermediate-stage amplifiers. They are loaded by varying the DC current through diodes CR1 and CR2. These are HPA 3034 PIN diodes. As the current increases, the resistance of these diodes decreases, thereby loading the collectors and reducing the gain. In addition, fine gain control is provided by varying the DC supply voltage.

5. 4. MAIN CHASSIS

The rest of the receiver consists of the power supply and the switching and display circuits. These unit are interconnected as shown in Figure 19.

5. 4. 1. POWER SUPPLY

The power supply used in the Type 136 Receiver is a modular unit designed to operate from a 115-volt, 50- to 400-Hz power supply. Changing

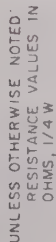


FIGURE 19. TYPE 136 RECEIVER, WIRING DIAGRAM

the jumper connections as indicated in the wiring diagram permits the unit to be operated from a 230-volt primary power source. The output of this power supply is +40 volts, and it is capable of delivering 300 ma. The regulation is less than 0.5 percent for line variations of ± 10 percent and load variations of one-half to full load.

5. 4. 2. OUTPUT INDICATOR

The output indicator of the Type 136 Receiver is meter M1, whose function is controlled by switch S1. When S1 is in position 1 (CRYSTAL 3 MA), the meter and its multiplier resistor R8 are placed across one of two 100-ohm current-sampling resistors in the preamplifier being used. The full-scale range of the meter in this application corresponds to 3 MA of crystal current. Polarity is reversed by double-pole double-throw toggle switch S2. The desired crystal is selected by toggle switch S3.

When S1 is in position 2 (DETECTOR NORM), the postamplifier detector current is applied to the meter through resistors R5, R6, and R7, which make up a 10-to-1 attenuator. Since the basic meter movement is 100 ua full scale, the postamplifier detector has to provide 1 ma of output current for full-scale deflection. The values of the resistors used in this attenuator are selected so that the load for the detector diode is always constant. The response of the output indicator is essentially linear; a 6-db decrease in signal level will cause the meter indication to fall to one-half of its original reading.

When S1 is placed in position 3 (DETECTOR EXP), the attenuator is bypassed, and the full detector output is applied to the meter. Normally, this would cause the meter to deflect off scale; however, at the same time that the attenuator is bypassed, a bucking current is applied to the meter, which subtracts 90 percent of the original full-scale current. This procedure increases the overall display sensitivity by a factor of ten. Diode CR1, a 1N87A germanium diode, is connected across the meter terminals to protect the meter from reverse overload currents.

5. 4. 3. GAIN CONTROL

Potentiometers R1 and R2 are the COARSE and FINE GAIN controls, respectively. Potentiometer R1 is actually two potentiometers with ganged shafts. This circuit is designed to compensate for the nonlinear voltage characteristic of the gain-control diodes. Potentiometer R2 simply varies the DC voltage applied to the postamplifier.

5. 4. 4. PREAMPLIFIER CONNECTION

All connections to the high-power or low-noise preamplifier, except the signal lead, are made through J1, the PREAMPLIFIER POWER jack. This front-panel receptacle is shielded from the rest of the receiver, and all leads are carefully filtered inside the shielded enclosure. This prevents feedback from the IF postamplifier to the preamplifier.

5. 5. LOW-NOISE PREAMPLIFIER

The low-noise preamplifier (Figure 20) is a two-stage 50-MHz tuned amplifier with a noise figure of less than 2.5 db and a gain of 50 db. The electrical connection to the input of this amplifier is by means of two spring clips. The input circuit of the low-noise first stage is designed to accept the output of a double-ended balanced mixer.

This mixer is of the type that uses two crystals--one of which has reversed polarity--producing two IF outputs that are in phase. Adapters (paragraph 5-7) provide a means of operating this preamplifier from a single-ended 50-ohm 50-MHz source or a single-ended 150-ohm, 50 MHz source.

The first stage of the preamplifier is noise matched to the crystal mixer impedance. Neutralization of the first stage is accomplished by means of capacitor C19 and a tap on transformer T1. The transistors used are low-noise 2N2996 germanium units. Internal filtering is provided on both the crystal-current lines and the B+ line.

5.6. HIGH-POWER PREAMPLIFIER

The high-power preamplifier (Figure 21) provides a wide RF attenuation measurement range through the selection of optimum values for gain, noise figure, and output power. The preamplifier output stage consists of two 2N2950 high-frequency power transistors operated in parallel. The intermediate stage also is a power transistor, whereas the first stage is a 2N3287.

Power circuits are generally noisy and although the front end is noise matched, the overall unit has a moderately high noise figure. However, the loss in dynamic range due to the higher noise level is insignificant compared with the increased range obtained by the high-power-handling capability.

The input circuit is designed in a manner similar to that of the low-noise preamplifier and can be operated from the same set of sources (mixers or adapters) as the low-noise preamplifier. The inter-stage coupling networks in the high-power preamplifier are similar to those used in the post-amplifier.

The preamplifier is tuned by collector inductance and the inter-stage capacitive transformers, such as C13 and C14 between Q1 and Q2. Careful attention has been paid to filtering the crystal current B+ lines because of the high power present in this circuit. In addition, a metallized flexible shielding gasket must always be used when the input circuits (either mixers or one of the adapters) are connected to the high-power preamplifier in order to prevent signal leakage.

5.7. PREAMPLIFIER ADAPTERS

The 50-ohm adapter (Figure 22a) mechanically mates with either the high-power or low-noise preamplifier. It permits these units to be used with 50-ohm 50-MHz signal sources. Internally, the adapter consists of an L matching section made up of a series capacitor and a shunt inductor. This matching section transforms the 50-ohm source impedance to 150 ohms.

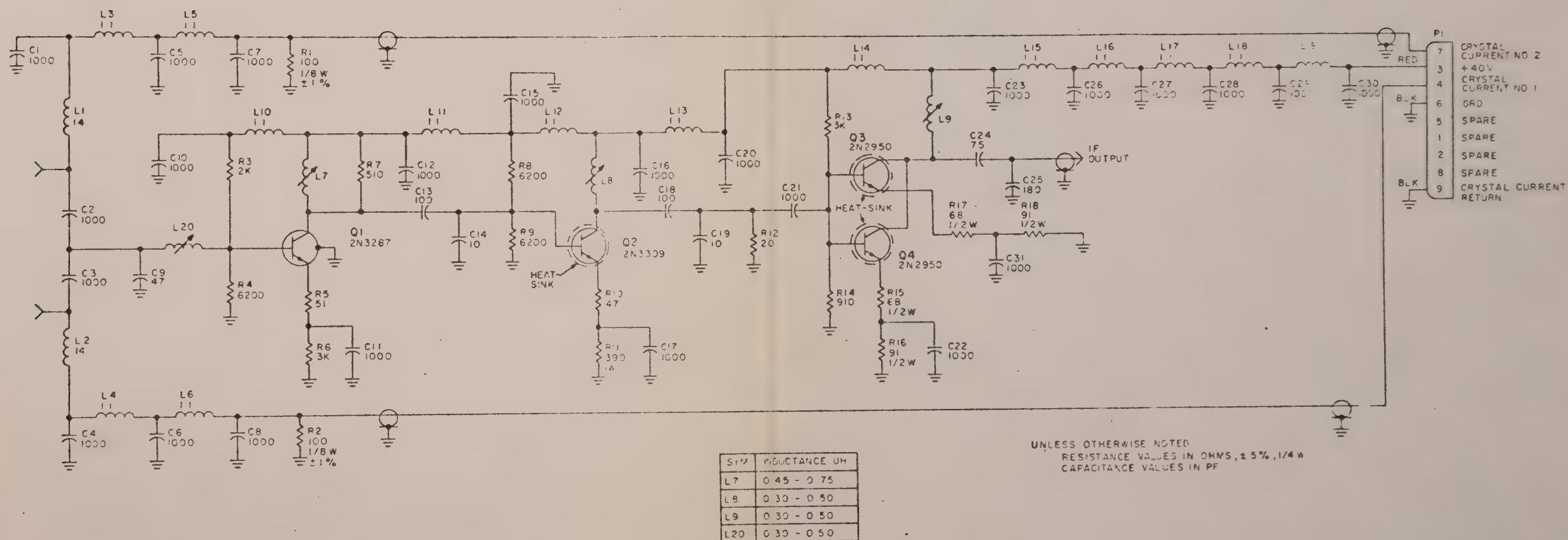


FIGURE 21. HIGH-POWER PREAMPLIFIER (P/N 13650, 30 MHz)
SCHEMATIC DIAGRAM

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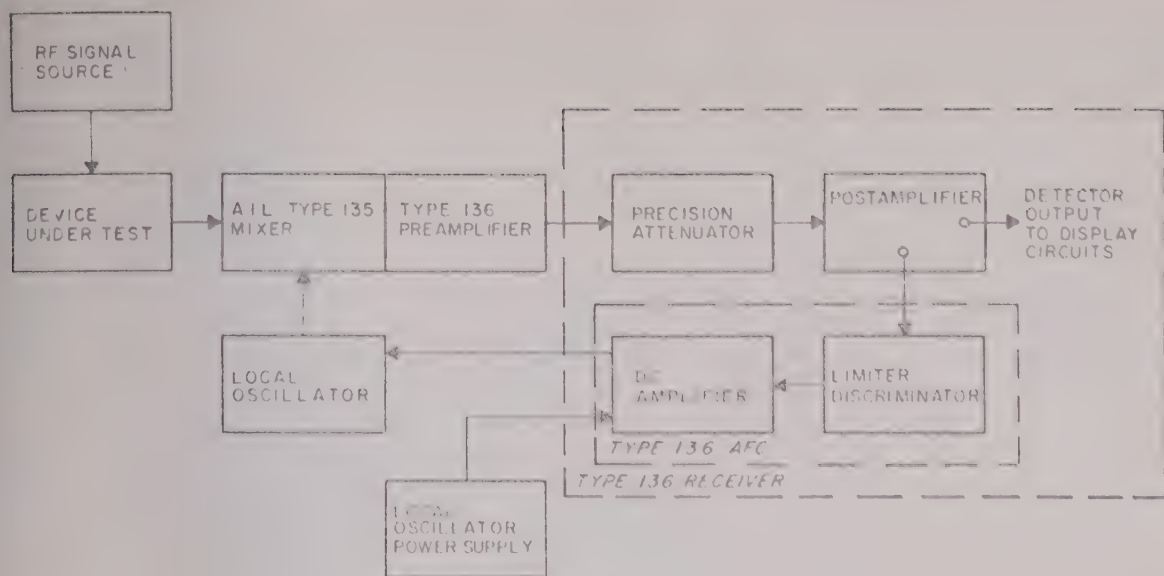


FIGURE 24. AFC SYSTEM, BLOCK DIAGRAM

The limiter section removes any amplitude variations on the signal, and the discriminator produces a DC voltage proportional to the deviation of the input signal from its desired center value. This DC correction voltage is amplified in the DC amplifier and applied to the local oscillator in a manner such that it opposes the original change in frequency, thereby minimizing any change in the IF input frequency.

5. 8. 1. LIMITER-DISCRIMINATOR

The limiter-discriminator assembly within the AFC unit is designed to: (1) remove amplitude variations from the signal, and (2) provide a DC output proportional to the deviation of the intermediate frequency from 30-MHz.

Referring to Figure 25, the IF output of the postamplifier is applied to amplifier Q201 through the matching section made up of capacitor C201 and indicator L201. The signal is further stepped up by transformer T201. Diodes CR201 and CR202 in the output of transformer T201 clip the signal and prevent its peak-to-peak amplitude from exceeding the conduction potential of the diodes.

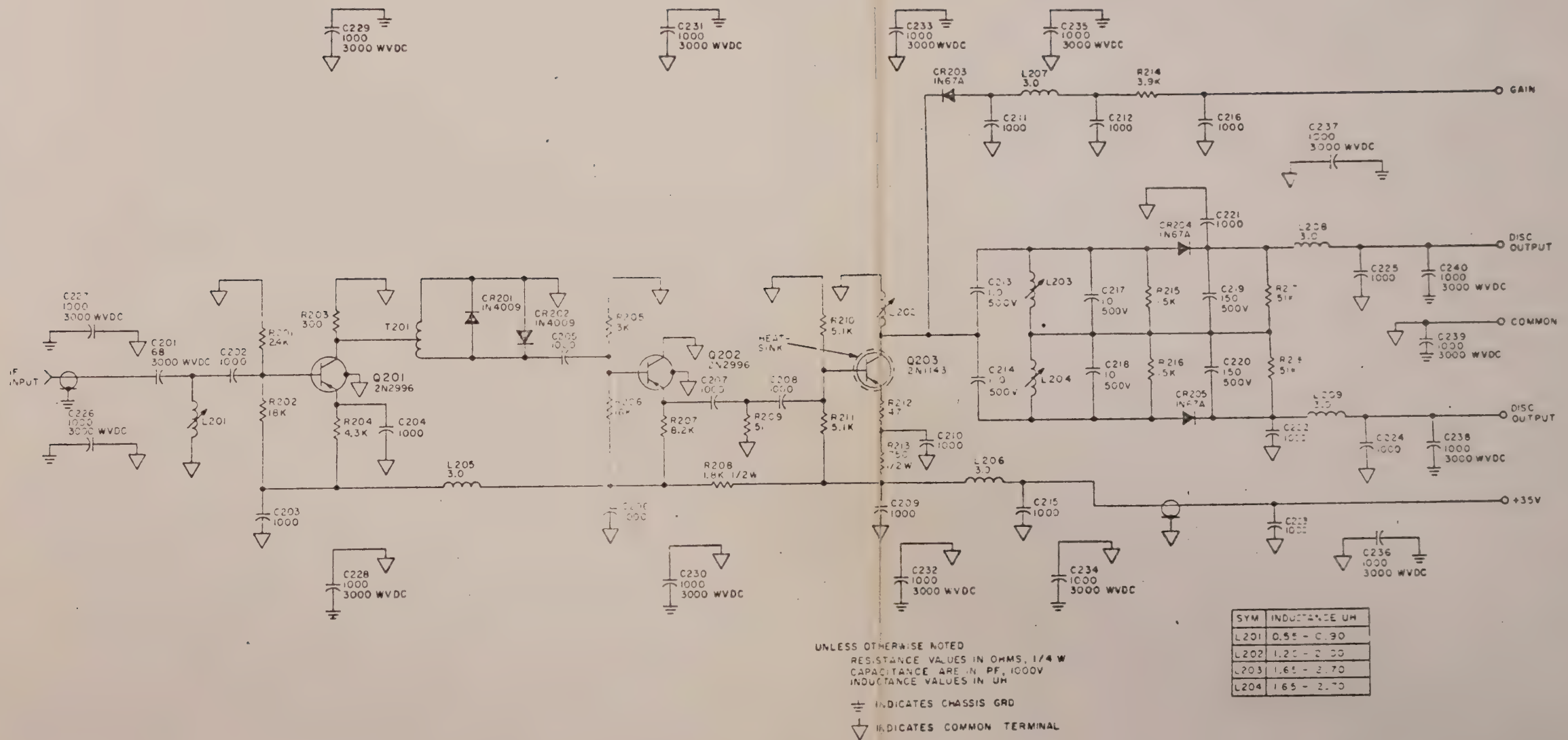


FIGURE 25. LIMITER-DISCRIMINATOR, SCHEMATIC DIAGRAM (30 MHz)

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5. 8. 2. DC AMPLIFIER

The output of the discriminator is applied to transistors Q301 and Q302 in the DC amplifier (Figure 26). These two transistors are connected as a dual emitter follower, thus minimizing the loading on the discriminator. Capacitor C301 helps shape the overall transfer characteristic of the AFC for stability purposes.

The emitter-follower output is amplified by transistors Q303 and Q304 and applied to the output amplifier made up of transistors Q305, Q306, and Q307. This circuit has a voltage gain of just less than unity; however, it has a high output-current capability. Transistor Q307 is a constant-current source that provides the load current when the output voltage is negative.

When the input to transistor Q305 is negative, short-circuit protection is provided by diode CR301. If a short circuit should occur, this diode clamps the base of transistor Q305 to the output voltage. The back-bias on the base-emitter junctions of transistors Q305 and Q306 is thus held to a few tenths of a volt. If a short circuit should occur when the input to transistor Q305 is positive, resistor R308 will limit the maximum base current and, therefore, the collector current of both output transistors; it will also hold it within the transistor ratings.

Thermistor R316 temperature stabilizes the AFC unit. The output of the AFC unit is through the IF filter made up of inductors L301 through L303 and capacitors C302 through C304. Capacitor C305 shapes the transfer characteristic of the system.

SECTION 6. MAINTENANCE INSTRUCTIONS

6.1. GENERAL

The use of solid-state components for all active elements and the selection of high quality components throughout assures a long, trouble-free life for this receiver. The entire receiver is guaranteed against defects in materials and workmanship, as stated in the warranty located inside the front cover of this handbook. Routine maintenance will generally be limited to lubrication of the precision attenuator as described below.

6.2. PRECISION ATTENUATOR

Maintenance of the precision attenuator is limited to lubrication of the drive mechanism semiannually. Crank the piston out about 1/2 inch from the fully seated position, then apply one drop of light instrument oil to the bearings and the piston. To distribute the oil, turn the drive shaft so that the piston is moved in and out over its full range.



Do not use an excessive amount of oil, because oil inside the piston or the sleeve can cause electrical malfunction. Do not attempt to disassemble the unit or make gear train adjustments. Return the unit to the manufacturer for any repairs.

6.3. MAIN CHASSIS

The wiring of all panel controls and indicators and the interwiring between subassemblies is shown in Figure 20.

6.4. POSTAMPLIFIER

The schematic diagram of the postamplifier is shown in Figure 19. Because of the long-term stability of this solid-state amplifier, all tuning adjustments are permanently secured. Retuning or other major repairs can best be handled by the manufacturer.

6.5. POWER SUPPLY P/N 207930

The power supply is a replaceable unit and should be returned to the manufacturer for repair.

6.6. FACTORY REPAIR

If the equipment is to be returned to the manufacturer for repair, please follow these instructions.

1. Write to the AIL Commercial Sales Department, giving complete information concerning the failure and the manner in which the equipment was being used when failure occurred. Include the unit TYPE and SERIAL numbers.
2. Special shipping instructions will be supplied by AIL. Pack and ship the equipment as directed. Transportation charges should be prepaid, and a failure report should be supplied with the equipment.

SECTION 7. LIST OF REPLACEABLE PARTS

7.1. MAIN CHASSIS (P/N 13600)

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
C1, 3, 5, 7	Capacitor, feedthrough	Allen-Bradley	SB4A
C2, 4, 6	Capacitor, standoff	Allen-Bradley	FB2B
CR1	Diode		IN87A
DS1	Lamp, neon	General Electric	NE-51
F1, 2	Fuse		FO2B250V1/2AS
J1	Connector, plug	Cannon	DE-9S
J2, 3, 9	Connector, BNC, straight	Amphenol	UG492A/U
J4	Connector, hood and clamp	Winchester	M4S-LSH10C
J5, 7	Connector, screw-on, plug	Sealectro Corp.	UG-1465
J8	Outlet, 3-wire, single	H. Hubbell, Inc.	5258
L1, 2, 3	Inductor, molded	Speers Carbon Co.	10101-1
M1	Meter	AIL	208277
P3, 9	Connector, BNC, cable plug	Sealectro	5027
P6	Cable and plug assy.	AIL	990050
R1	Resistor, variable (dual JT)	AIL	115289-15
R2	Resistor, variable	AIL	115289-12
R3	Resistor, fixed	Ward Leonard	5SX
R4	Resistor, fixed, comp, 30K, 1/4 W		RC07GF303J
R5, 6, 7, 8	Resistor, fixed	Ward Leonard	1SX
R9	Resistor, fixed comp, 3.9K 1/4 W		RC07GF392J
S1	Switch, rotary	Standard Grigsby	Type 4MF

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
S2	Switch, small motor DPDT	Cutler-Hammer	8363
S3	Switch, small motor SPDT	Cutler-Hammer	8282K14
S4	Switch, small motor, DPST	Cutler-Hammer	8370
XDS1	Pilot light assembly	Dialight	52408
XF1, 2	Fuseholder	Bussman	HKP-EH
	Attenuator, precision	AIL	03131
	Adapter, connector	3- to 2-wire	990076
7.2.	<u>POSTAMPLIFIER (P/N 214128, 50 MHz)</u>		
C1	Capacitor, ceramic	Erie	(208722-4)
C2	Capacitor, trimmer	Erie	557-091-N1500 (P3PO)10-75Pf (109R)
C3	Capacitor, ceramic, 180 pf $\pm 10\%$	---	CK05CW181K
C4, 5, 6, 9, 10, 13, 14, 17 through 21, 25, 26, 30, 33 through 39	Capacitor, ceramic, 1000 pf $\pm 10\%$	---	CK05CW102K
C7	Capacitor, ceramic, 220pf $\pm 10\%$	---	CK05CW221K
C8	Capacitor, ceramic, 270 pf $\pm 10\%$	---	CK-5CW271K
C11, 12, 15, 16	Capacitor, ceramic, 27 pf $\pm 10\%$	---	CK05CW270K
C22	Capacitor, ceramic	Erie	CK05CW680K
C23	Capacitor, ceramic	Erie	(208722-4)
C24	Capacitor, ceramic 56 pf $\pm 10\%$	---	CK05CW560K
C27	Capacitor, ceramic 82 pf $\pm 10\%$	---	CK05CW820K

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
C28	Capacitor, ceramic 100 pf $\pm 10\%$	Erie	N1500
C29	Capacitor, ceramic 680 pf $\pm 10\%$	Erie	CK05CW681K
C31, 32	Capacitor, electrolytic	Sprague	TE1205
C40	Capacitor, ceramic 100 pf $\pm 10\%$	Erie	CK05CW101K
C41	Capacitor, ceramic 56 pf $\pm 10\%$	Erie	CK05CW560K
CR1, 2	Diode	---	HPA 3034
CR3	Diode	---	IN87A
L1, 3	Inductor, variable	AIL	118244-11 (1 turn removed)
L2, 13 through 16, 5, 7, 8, 9	Inductor, molded	Speers Carbon Co.	10101-1
L4, 6, 12	Inductor, variable	AIL	118244-1
L10	Inductor, variable	AIL	118244-11
L11	Inductor, molded	Speers Carbon Co.	10100-2
P2	Plug, BNC to RG188/U cable	Sealectro Corp.	5027
P4	Connector, plug, 4 pin	Winchester	4MP-LRN
P5, 7	Connector, RF	Sealectro	50-043-4300
Q1 through 4	Transistor		2N2996
Q5	Transistor	Texas Instru- ments only	2N1141
Q6, 7	Transistor		2N706
R1	Resistor, fixed, comp, 2.7K $\pm 5\%$ 1/4 W	---	RC07GF272J
R2	Resistor, fixed, comp; 1.5K $\pm 5\%$ 1/4 W	---	RC07GF152J
R3, 9, 10, 13, 14	Resistor, fixed, comp, 2K $\pm 5\%$ 1/4 W	---	RC07GF202J
R4, 5, 6	Resistor, fixed, comp, 620 ohms $\pm 5\%$ 1/4 W	---	RC07GF621J
R7, 11, 15	Resistor, fixed, comp, 680 ohms $\pm 5\%$ 1/4 W	---	RC07GF681J

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
R8, 12, 16	Resistor, fixed, comp, 820 ohms $\pm 5\%$ 1/4 W	---	RC07GF821J
R17, 18	Resistor, fixed, comp, 1K $\pm 5\%$ 1/4 W	---	RC07GF102J
R19	Resistor, fixed, comp, 560 ohms $\pm 5\%$ 1/4 W	---	RC07GF561J
R20	Resistor, fixed, comp, 1.3K $\pm 5\%$ 1/4 W	---	RC07GF132J
R21, 25, 26	Resistor, fixed, comp, 5.6K $\pm 5\%$ 1/4 W	---	RC07GF562J
R22, 28	Resistor, fixed, comp, 1.2K $\pm 5\%$ 1/4 W	---	RC07GF122J
R23, 27	Resistor, fixed, comp, 3.3K $\pm 5\%$ 1/4 W	---	RC07GF332J
R29, 30	Resistor, fixed, comp, 11 ohms $\pm 5\%$ 1/4 W	---	RC07GF110J
R31	Resistor, fixed, comp, 240 ohms $\pm 5\%$ 1/4 W	---	RC07GF241J

7.3 LOW NOISE PREAMPLIFIER (P/N 214126, 50 MHz)

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
C1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 14, 15, 17	Capacitor, Disc Ceramic 1000 pf, 1000 V.	Centralab	DD-102
C12	Capacitor, Ceramicon 100 pf, 200 V, N750	Erie Resistor Corp.	208722-2
C13	Capacitor, Ceramicon 27 pf, 200 V	Erie Resistor Corp.	CK05CW270K
C16	Capacitor, Ceramicon 62 pf, 200 V	Erie Resistor Corp.	NP08141
C18	Capacitor, Ceramic 120 pf, 300 V, N750	AIL	208722-2
C19	Capacitor, Variable 2-8 pf	AIL	298934-1

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
R1, R7	Resistor, Fixed, Comp 3K, $\pm 5\%$, 1/4W	----	RC07GF302J
R2, R8	Resistor, Fixed, Comp 3.6K $\pm 5\%$, 1/4W	---	RC07GF362J
R3	Resistor, Fixed, Comp 1.8K $\pm 5\%$, 1/4W	---	RC07GF182J
R4	Resistor, Fixed, Comp 270 $\pm 5\%$, 1/4W	---	RC07GF271J
R5, R6	Resistor, Fixed, Comp 100 $\pm 5\%$, 1/4W	---	RC07GF101J
R11	Resistor, Fixed, Comp 510 $\pm 5\%$, 1/4W	---	RC07GF511J
R12	Resistor, Fixed, Comp 750 $\pm 5\%$, 1W	---	RC32GF751J
R10	Resistor, Fixed, Comp 1K $\pm 5\%$, 1/4W	---	RC07GF102J
Q1	Transistor	AIL	209376
Q2	Transistor	---	2N2996
L1, L2	Inductor, Molded, 14 uh	AIL	115297-2
L3, L5, L6, L7, L9	Inductor, Molded, 1.1 uh	Speers Carbon Co.	10101-1
L4	Inductor, Variable	AIL	118244-1
L10	Inductor, Variable	AIL	118244-1 (2 turns removed)
T1	Transformer, RF	AIL	208935
J1	Connector, Coaxial, BNC	---	UG625/U
P1	Connector, Plug, Elec. Male	Cannon	DE-9P
CR1	Zener Diode		1N965B
7.4.	<u>50-OHM ADAPTER (P/N 214127, 50 MHz)</u>		
C1	Capacitor, Ceramic 39 pf, 50 V	Corning	TY06-390J
L1	Inductor, Variable	AIL	118244-2

7.5. 150-OHM ADAPTER (P/N 208550)

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
C1	Capacitor, Ceramic 1000 pf	---	CK60AW102M
L1	Inductor, Variable	AIL	118244-6

7.6. HIGH-POWER PREAMPLIFIER (P/N 013650, 30 MHz)

C1 through 8, 10, 11, 12, 15, 16, 17, 20 through 23 26 through 31	Capacitor, disk, ceramic	Centralab	DD102
C9	Capacitor, disk, ceramic, 47 pf	---	CK05CW470K
C13, 18	Capacitor, ceramicon	Erie	NPO 8151
C14, 19	Capacitor, ceramicon	Erie	865-000-P3K- 100J
C24	Capacitor, ceramicon	Erie	NPO 8141
C25	Capacitor, ceramicon, 180 pf	---	CK05CW181K
L1, 2	Inductor, molded	Speers Carbon	10102-1
L3 through 6, 10 through 19	Inductor, molded	Speers Carbon	10101-1
L7	Inductor, variable	AIL	118244-2
L8, 9, 20	Inductor, variable	AIL	118244-1
P1	Connector, plug, elec., male	Cannon Elec. Co.	DE-9P
Q1	Transistor	---	2N3287
Q2	Transistor	---	2N3309
Q3, 4	Transistor	Motorola	2N2950
R1, 2	Resistor, fixed, comp, 100 ohms $\pm 5\%$ 1/4 W	---	RC07GF101J

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
R3	Resistor, fixed, comp, 2K $\pm 5\%$ 1/4 W	---	RC07GF202J
R4	Resistor, fixed, comp, 6.2K $\pm 5\%$ 1/4 W	---	RC07GF602J
R5	Resistor, fixed, comp, 51 ohms $\pm 5\%$ 1/4 W	---	RC07GF510J
R6, 13	Resistor, fixed, comp, 3K $\pm 5\%$ 1/4 W	---	RC07GF302J
R7	Resistor, fixed, comp, 510 ohms $\pm 5\%$ 1/4 W	---	RC07GF511J
R8, 9	Resistor, fixed, comp, 6.2K $\pm 5\%$ 1/4 W	---	RC07GF622J
R10	Resistor, fixed, comp, 47 ohms $\pm 5\%$ 1/4 W	---	RC07GF470J
R11	Resistor, fixed, comp, 390 ohms $\pm 5\%$ 1 W	---	RC32GF391J
R12	Resistor, fixed, comp, 20 ohms $\pm 5\%$ 1/4 W	---	RC07GF200J
R14	Resistor, fixed, comp, 910 ohms $\pm 5\%$ 1/4 W	---	RC07GF911J
R15, 17	Resistor, fixed, comp, 68 ohms $\pm 5\%$ 1/4 W	---	RC07GF680J
R16, 18	Resistor, fixed, comp, 91 ohms $\pm 5\%$ 1/4 W	---	RC07GF910J

7.7. AUTOMATIC FREQUENCY CONTROL (P/N 013670, 30 MHz)

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
C201	Capacitor, fixed, ceramic	Erie	858-000-S3B- 680
C202 through 212, 215, 216, C221 through 225 C302 through 304	Capacitor, disk, ceramic	Centralab	DD-102

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
C213, 214	Capacitor, fixed, tubular	Stackpole	Type GA
C217, 218	Capacitor, disk, ceramic	Erie	831-000-P3K-100J
C219, 220	Capacitor, disk, ceramic 150 pf, 500 v	---	CK60BX151K
C226 through 237, 238 through 240	Capacitor, H.V., disk, ceramic	Erie	858-003-Y52-102
C301	Capacitor, metalized paper	Aerovox Corp.	P8292ZN13
	Capacitor, Electrolytic	Cornell-Dubilier	BR60-150
CR201, 202	Semiconductor device diode	---	1N4009
CR203 through 205	Semiconductor Device diode	---	1N67
CR301	Diode	---	1N625
DS101	Lamp, neon	General Electric	NE-51
F101, 102	Fuse 0.5 ampere	---	FO2b250V1/2AS
J10, 11	Connector	UG909/U	UG909/U
L201	Inductor, variable	AIL	118244-3
L202	Inductor, variable	AIL	118244-5
L203, 204	Inductor, variable	AIL	118244-6
L205 through 209, 302, 303	Inductor, molded	Speers Carbon Co.	10100-2
L301	Coil, video, peaking	Miller	6181
M1	Meter, panel	AIL	208369
P8	Cable and plug assembly	Phalo Plastics	---
P9, 12, 13	Connector	---	UG88/U
Q201, 202	Transistor	---	2N2996
Q203	Transistor	---	2N1143
Q301, 302	Transistor	Amperex	ME213
Q303	Transistor	---	2N1375

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
Q304, 305	Transistor	Texas Instrument	T11481
Q306, 307	Transistor	---	2N3441
R101	Resistor, variable	AIL	115289-13
R102	Resistor, variable	AIL	115289-14
R103	Resistor, fixed, comp, 1K $\pm 5\%$ 1/2 W	---	RC20GF102J
R201	Resistor, fixed, comp, 2.4K $\pm 5\%$ 1/4 W	---	RC07GF242J
R202	Resistor, fixed, comp, 18K $\pm 5\%$ 1/4 W	---	RC07GF183J
R203	Resistor, fixed, comp, 300 ohms $\pm 5\%$ 1/4 W	---	RC07GF301J
R204	Resistor, fixed, comp, 4.3K $\pm 5\%$ 1/4 W	---	RC07GF432J
R205	Resistor, fixed, comp, 3K $\pm 5\%$ 1/4 W	---	RC07GF302J
R206	Resistor, fixed, comp, 16K $\pm 5\%$ 1/4 W	---	RC07GF163J
R207	Resistor, fixed, comp, 8.2K $\pm 5\%$ 1/4 W	---	RC07GF822J
R208	Resistor, fixed, comp, 1.8K $\pm 5\%$ 1/4 W	---	RC07GF182J
R209	Resistor, fixed, comp, 51 ohms $\pm 5\%$ 1/4 W	---	RC07GF510J
R210, 211	Resistor, fixed, comp, 5.1K $\pm 5\%$ 1/4 W	---	RC07GF512J
R212	Resistor, fixed, comp, 10 ohms $\pm 5\%$ 1/4 W	---	RC07GF100J
R213	Resistor, fixed, comp, 750 ohms $\pm 5\%$ 1/4 W	---	RC07GF751J
R214	Resistor, fixed, comp, 3.9K $\pm 5\%$ 1/4 W	---	RC07GF392J
R215, 216	Resistor, fixed, comp, 15K $\pm 5\%$ 1/4 W	---	RC07GF153J

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
R217, 218	Resistor, fixed, comp, 51K $\pm 5\%$ 1/4 W	---	RC07GF513J
R301	Resistor, fixed, comp, 3.6K $\pm 5\%$ 1 W	---	RC32GF362J
R302	Resistor, fixed, comp, 5.6 meg $\pm 5\%$ 1/4 W	---	RC07GF565J
R303	Resistor, fixed, comp, 30K $\pm 5\%$ 1/4 W	---	RC07GF303J
R304	Resistor, fixed, comp, 33K $\pm 5\%$ 1/4 W	---	RC07GF333J
R305, 306	Resistor, fixed, comp, 390 ohms $\pm 5\%$ 1/4 W	---	RC07GF391J
R307	Resistor, fixed, comp, 2K $\pm 5\%$ 1/4 W	---	RC07GF202J
R308	Resistor, fixed, comp, 20K $\pm 5\%$ 1/4 W	---	RC07GF203J
R309	Resistor, fixed, comp, 110K $\pm 5\%$ 1/4 W	---	RC07GF114J
R310	Resistor, fixed, comp, 330 ohms $\pm 5\%$ 1/4 W	---	RC07GF331J
R311	Resistor, fixed, comp, 1.8K $\pm 5\%$ 1/4 W	---	RC32GF182J
R312	Resistor, fixed, comp, 110K $\pm 5\%$ 1/4 W	---	RC07GF114J
R313	Resistor, fixed, comp, 91 ohms $\pm 5\%$ 2W	---	RC42GF910J
R314	Resistor, fixed, comp, 130 ohms 25% 1/2 W	---	RC20GF131J
R315	Resistor, fixed, comp, 560K $\pm 5\%$ 1/4 W	---	RC07GF564J
R316	Thermistor, disk	AIL	208307-3
S101	Switch, 1 pole, 2 posi- tion	Standard Grigsby	Type 4MF
S102	Switch, small motor, DPST	Cutler-Hammer	8370

<u>Reference Symbol</u>	<u>Description</u>	<u>Manufacturer</u>	<u>Part Number</u>
T201	Transformer	AIL	208410
XDS101	Pilot light assembly	Cutler-Hammer	8363
XF101, 102	Fuseholder	Bussman Mfg.	HKP-EH

APPENDIX A

TECHNIQUES OF ATTENUATION MEASUREMENT

1. INSERTION-LOSS DEFINITION

The insertion loss of a two-port network can be defined as that decrease in transmitted power that occurs when a uniform transmission line, having a matched source at one end and a matched load at the other end, is interrupted by the insertion of the network. Referring to the circuit of Figure A-1, insertion loss L can be expressed in terms of the relation between the power available from the matched generator P_G and the power absorbed by the matched load P_L . This relation is shown in normalized form in equation A-1

$$L = 1 - \frac{P_L}{P_G} \quad (A-1)$$

The above definition of insertion loss includes two separate effects: attenuation, and reflection loss. Some of the power entering the network is dissipated within the network. This loss can be defined as the attenuation of the network. In addition, if there is an impedance mismatch at either one or both ports of the network, a portion of the incident power is reflected back toward the generator, causing losses that are referred to as reflection losses.

Insertion loss can be expressed as the sum of these losses:

$$L = L_A + L_i + L_o \quad (A-2)$$

where

L = Insertion loss (db)

L_A = Loss due to attenuation (db)

L_i = Loss due to mismatch at the attenuator input (db)

L_o = Loss due to mismatch at the attenuator output (db)

2. MISMATCH ERRORS IN ATTENUATION MEASUREMENT

The reflection losses at the two ports of the network vary, depending on the actual source and load impedances in the measurement system. These variations cause an uncertainty whose limits can be calculated as follows.

The reflection losses in the matched system of Figure A-1 are equal to

$$L_1 = \left| r_1 \right|^2 \quad (\text{A-3})$$

$$L_o = \left| r_o \right|^2 \quad (\text{A-4})$$

where

r_1 = Reflection coefficient of attenuator input

r_o = Reflection coefficient of attenuator output

In the practical measurement system (Figure 2) the reflection losses may differ from the values given above because of the mismatched generator and load. The measured reflection loss at the input port may be either greater or less than the desired value and will fall within the following limits:

$$L_1 = \left| r_1 \right|^2 \quad (\text{A-5})$$

where

$$r_1 = \frac{S_1 - 1}{S_1 + 1} \quad (\text{A-6})$$

and

$$\frac{S_G}{S_i} \leq S_1 \leq S_G S_i \quad (\text{A-7})$$

L_1 = Measured reflection losses at attenuator input

S_1 = Effective SWR of combination of generator-output and attenuator-input impedances

S_i = SWR of attenuator input impedance

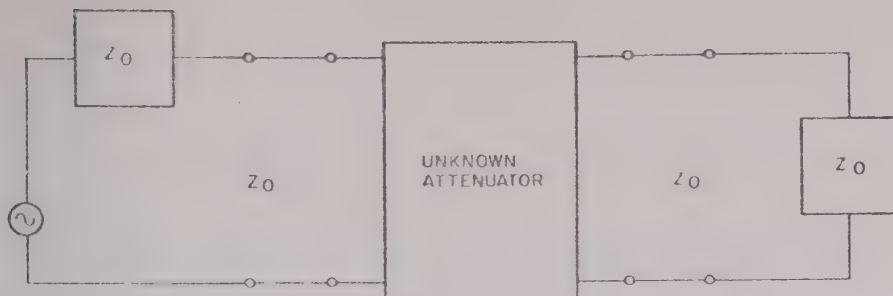
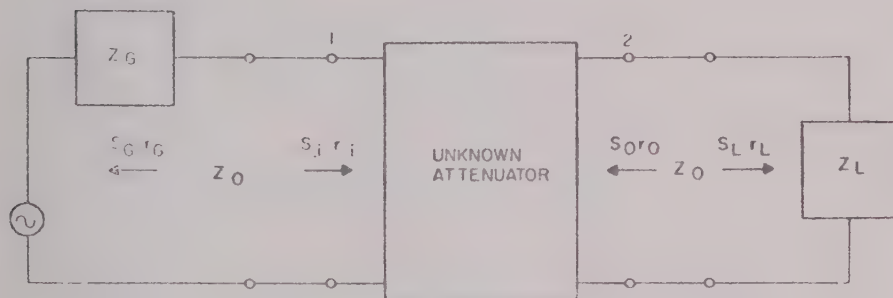
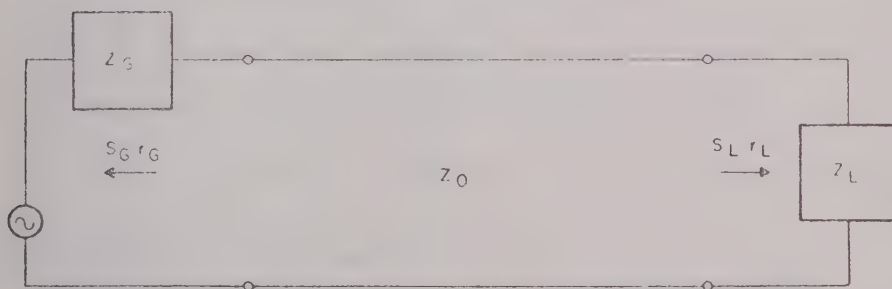


FIGURE A-1. ASSUMED CONDITIONS FOR DEFINITION OF INSERTION LOSS



A. ATTENUATOR INSERTED



B. ATTENUATOR OMITTED

FIGURE A-2. ACTUAL CONDITIONS FOR MEASUREMENT OF INSERTION LOSS

S_G = SWR of generator output impedance

r_1 = Reflection coefficient corresponding to S_1

The difference between the measured mismatch loss and the theoretical mismatch loss constitutes an uncertainty E_1 .

$$E_1 = L_1 - L_i \quad (A-8)$$

$$E_1 = \left| r_1 \right|^2 - \left| r_i \right|^2 \quad (A-9)$$

Similarly, a corresponding uncertainty in measurement E_2 occurs as a result of the mismatch of the load.

$$E_2 = \left| r_2 \right|^2 - \left| r_o \right|^2 \quad (A-10)$$

where

$$r_2 = \frac{S_2 - 1}{S_2 + 1} \quad (A-11)$$

$$\frac{S_o}{S_L} \leq S_2 \leq S_o S_L \quad (A-12)$$

S_o = SWR of the attenuator output impedance

S_L = SWR of the load impedance

S_2 = Effective SWR of the combination of the load
and the attenuator output impedances.

r_2 = Reflection coefficient corresponding to S_2

When reading the reference power level with the equipment arranged as shown in Figure 2b, an additional uncertainty in measurement occurs when the generator and load are mismatched;

$$E_R = \left| r_R \right|^2 \quad (A-13)$$

where

$$r_R = \frac{S_R - 1}{S_R + 1} \quad (A-14)$$

$$\frac{S_G}{S_L} \leq S_R \leq S_G S_L \quad (A-15)$$

S_R = Effective SWR of the mismatched generator and load

R = Reflection coefficient corresponding to S_R

The combined effect E of the uncertainties described above is equal to:

$$E = \frac{E_1 E_2}{E_R} \quad (A-16)$$

or, when all terms are expressed in db,

$$E' = E'_1 + E'_2 - E'_R \quad (A-17)$$

where

$$E'_1 = 10 \log \left(\frac{1}{1 - E_1} \right) \text{ etc.} \quad (A-18)$$

A calculation of the uncertainty of a measurement is shown in the following example. Assuming:

$$S_G = 1.3$$

$$S_L = 1.16$$

$$S_i = S_o = 1.2$$

From equations 6 and 7,

$$0.039 \leq r_1 \leq 0.219$$

$$r_i = 0.0909$$

Then, from equation 9,

$$-0.006 \leq E_1 \leq 0.040$$

The corresponding db values can be computed from equation A-18.

$$0.027 \leq E'_1 \leq 0.178 \text{ db}$$

Similarly, from equations A-10, A-11, A-12, and A-18

$$-0.036 \leq E'_2 \leq 0.085 \text{ db}$$

and from equations A-13, A-14, A-15, and A-18

$$0.013 \leq E'_R \leq 0.191 \text{ db}$$

The extreme values of the uncertainty E' can be found by combining the above values in accordance with equation A-17.

$$E' = 0.178 + 0.085 - 0.013 = 0.250 \text{ db (maximum positive)}$$

$$E' = -0.027 - 0.036 - 0.043 = -0.106 \text{ db (maximum negative)}$$

B. REDUCTION OF MISMATCH ERRORS

The use of a matched attenuator between a mismatched generator or load and the measurement circuit will reduce the SWR of these components. The improved SWR is related to the original SWR as follows:

$$S = \frac{A(S_G + 1) + (S_G - 1)}{A(S_G + 1) - (S_G - 1)} \quad (\text{A-19})$$

where S = Improved SWR

S_G = Original SWR of the generator (or load)

$$A = \text{Attenuator loss} \left(\frac{P_{\text{in}}}{P_{\text{out}}} \right)$$

The attenuator should be placed immediately adjacent to the unknown attenuator in order to reduce reflections from all possible sources in the "generator" or "load" sections of the measurement system.

The following example illustrates the improvement obtained in the SWR of a signal generator by the use of a perfectly matched 6-db attenuator.

$$\text{If } S_G = 3$$

$$\text{and } A = 4$$

then, from equation A-19:

$$S = 1.3$$

Ferrite isolators used in place of the matched attenuators will also provide an improved SWR and, because of their low insertion loss, there will be very little reduction in the attenuation measurement range. The main disadvantages of the ferrite isolators are their high cost and limited frequency range.

An alternative method of reducing the mismatch of the generator and load sections of the measurement system is to use a tuner on each side of the unknown attenuator as shown in Figure A-3.

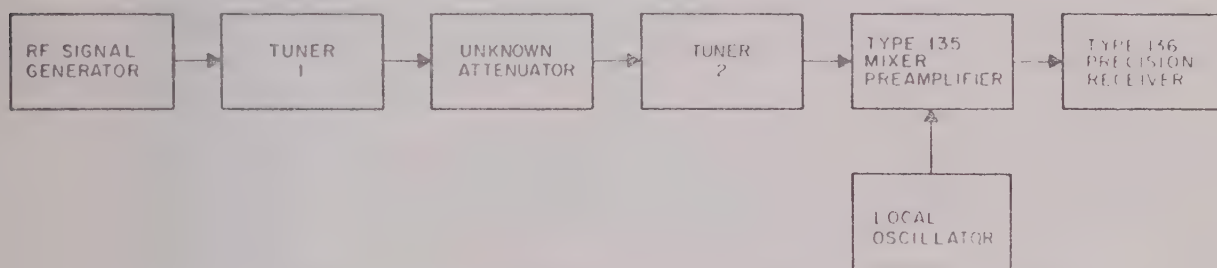


FIGURE A-3. USE OF TUNERS IN ATTENUATION MEASUREMENT

To adjust tuner 2, a slotted line can be inserted in place of the unknown attenuator. The local oscillator should be set to the desired operating frequency and its level adjusted for proper crystal current in the mixer. The RF signal generator should be modulated by 1 kHz to provide a signal for the SWR indicator used with the slotted line. Tuner 2 should then be adjusted until the indicated SWR is reduced to the desired level. An SWR of 1.02 should be obtainable.

Tuner 1 can be adjusted in a similar manner by turning off the RF signal generator, disconnecting tuner 2 from the slotted line, and feeding the output of a second signal generator into this port of the slotted line. The second generator must be tuned to the same operating frequency as the first generator and must be modulated by 1 kHz. If a ferrite isolator is used between the signal generator and tuner 1, the signal generator can be disconnected from the isolator and used as the signal source for the adjustment of

tuner 1. In addition, the use of the isolator makes it possible to change the setting of the signal generator output attenuator without readjusting the tuner.

4. SYSTEM NONLINEARITY ERRORS

In any IF-substitution measurement of RF attenuation, the accuracy is dependent upon the linearity of the circuit elements between the unknown attenuator and the precision IF attenuator. The combination of the Type 135 mixer and the Type 136 high-power IF preamplifier has been designed to provide a very wide linear range.

The linearity of the system can be checked by making a series of measurements of a fixed RF attenuator over a range of input signal levels. The procedure is as follows:

1. Measure the attenuation of a fixed RF attenuator of approximately 20 db, using an RF signal level somewhere near the center of the linear operating range of the system.
2. Adjust the RF signal generator output to a slightly higher level.
3. Using the same reference setting of the precision attenuator as was used in step 1, adjust the receiver gain control to obtain the same output reference reading as was used in step 1.
4. Measure the unknown attenuator at this new signal level.
5. Remeasure the unknown attenuator at other signal levels over the range of interest.

Readings taken in the linear range of the system will be identical. As the nonlinear areas are approached at each end of the range, lower attenuation readings will be obtained. The difference between these reduced readings and the correct attenuation, measured in the linear range, is a measure of the system error caused by the nonlinearity of the mixer-preamplifier at the signal level of the measurement.

5. SIGNAL LEAKAGE ERRORS

When attenuation measurements are made over a large range, errors may occur as a result of signal leakage. During an attenuation measurement, any leakage of the signal around either the RF attenuator or the precision IF

attenuator will cause an error. Figure A-4 shows a leakage path around an unknown attenuator.

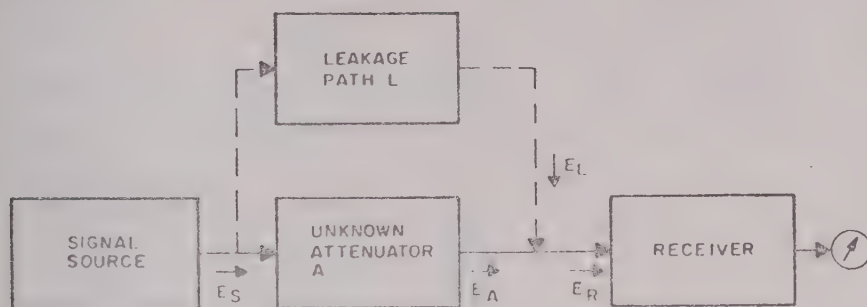


FIGURE A-4. LEAKAGE PATH AROUND AN UNKNOWN ATTENUATOR

The effect of the signal transmitted through the loosely coupled leakage path can be calculated as follows:

$$A = \frac{E_S}{E_A}$$

$$L = \frac{E_S}{E_L}$$

where

A = Loss of the unknown attenuator

L = Loss of the leakage path

E_S = Source voltage

E_A = Output voltage of the attenuator

E_L = Output voltage of the leakage path

Since

$$E_R = E_A + E_L$$

$$E_R = \frac{E_S}{A} + \frac{E_S}{L}$$

and

$$E_R = \frac{E_S}{A} \left(1 \pm \frac{A}{L}\right)$$

Since the voltages E_A and E_L are vector quantities whose relative phase is unpredictable, the quantity $\frac{A}{L}$ represents a maximum uncertainty in the measurement of the unknown attenuation A . The quantities A and L are expressed here as voltage ratios and, therefore, the uncertainty E may be expressed in decibels as

$$E = 20 \log \left(1 \pm \frac{A}{L}\right)$$

As an example, if the signal transmitted through the leakage path is 20 db lower than that through the unknown attenuator ($A/L = 0.1$), then the uncertainty of measurement is within the limits of ± 0.8 db.

The actual leakage in a measurement system can be determined by removing the unknown attenuation, terminating both ports of the measurement system, and measuring the decrease in signal level at the receiver as shown in Figure A-5.

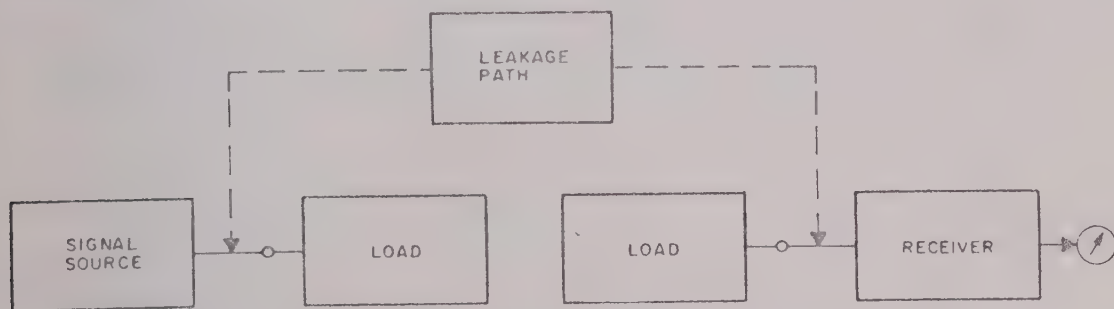


FIGURE A-5. MEASUREMENT OF LEAKAGE PATH

Careful attention to the selection and arrangement of the component parts of the measurement system can reduce leakage. For instance, coaxial connectors must be in good condition and be properly fitted to the cables, waveguide flanges must be in good condition and properly mated, and the signal source must be adequately shielded and its power line well filtered.

APPENDIX B

METHODS OF NOISE TEMPERATURE MEASUREMENT

1. NOISE TEMPERATURE THEORY

A discussion of the theory of noise temperature measurement requires first a definition of the terms and quantities involved. This section is devoted to a brief development of the basic relations between noise power, effective input noise temperature, and noise figure. Further information and more detailed derivations can be obtained by consulting the references listed at the end of this Appendix.

a. NOISE POWER

Throughout this section, reference is made to noise power originating from various sources. The definitions and measurements are in terms of the equivalent thermal noise power, that is, the noise generated as a result of the thermally agitated, random motion of electrons in a conductor. This is sometimes referred to as Johnson noise. Nyquist's theorem defines the relation between noise power and temperature. The result is given in equation B-1.

$$N = KT \quad (B-1)$$

where

N = noise power per unit bandwidth which would be delivered to a conjugately matched load,

K = Boltzmann's constant (1.38×10^{-23} joules/°K),

T = temperature in degrees Kelvin.

Equation B-1 states that the noise power per unit bandwidth available at the terminals of a resistor is directly proportional to the absolute temperature. Note that N is independent of the resistance value and the type of resistor.

b. EFFECTIVE INPUT NOISE TEMPERATURE (T_e)

The available noise power at the output of a network with multiple input ports and a single output port can be given as:

$$N_o = N'_{i1} G_1 + N'_{i2} G_2 + N'_{i3} G_3 \text{ ----- } + N'_{in} G_n \quad (\text{B-2})$$

where

N'_{in} = noise power available from all sources at the nth input port,

G_n = ratio of the signal power delivered to the load to the signal power available at the nth input port (transducer gain).

The term N'_{in} can be expressed as the sum of two components:

$$N'_{in} = N_{in} + N_e \quad (\text{B-3})$$

The term N_e represents the internal noise of the network. Note that this quantity is assigned simultaneously to all input ports. A noise temperature (T_{in}) can be assigned to each of these components in accordance with equation B-1;

$$N'_{in} = K (T_{in} + T_e) \quad (\text{B-4})$$

and

$$N_o = K \left[(T_{i1} + T_e) G_1 + (T_{i2} + T_e) G_2 \text{ ---- } + (T_{in} + T_e) G_n \right] \quad (\text{B-5})$$

The term T_e is called the effective input noise temperature of the network, and it is a measure of its internal noisiness. If the terminations at all inport ports are at the same temperature, then

$$N_o = K(T_i + T_e) \sum_{n=1}^n G_n \quad (\text{B-6})$$

c. OPERATING NOISE TEMPERATURE (T_{op})

As shown above, effective input noise temperature (T_e) is a measure of the internal noisiness of a network. In contrast, operating noise

temperature (T_{op}) is a measure of the overall noise performance of a receiving system in its actual operating environment. This quantity can be defined for a system, where one input port is designated the primary signal channel, in terms of the total noise output power of the system;

$$N_o = K T_{op} G_s \quad (B-7)$$

where

G_s = gain of the primary signal channel.

Operating noise temperature can be related to effective input noise temperature by combining equations B-6 and B-7;

$$T_{op} = (T_i + T_e) \sum_{n=1}^n \frac{G_n}{G_s} \quad (B-8)$$

If the system has only one channel,

$$T_{op} = (T_i + T_e) \quad (B-9)$$

One multiple-channel system of particular interest is the heterodyne receiver. Although there may be only one physical input port, there are two possible frequency transformations and, hence, two distinct channels. If one transformation is designated the signal channel and the other, the image, then:

$$T_{op} = (T_i + T_e) \left(1 + \frac{G_{im}}{G_{sig}} \right) \quad (B-10)$$

d. NOISE FIGURE

Noise figure is probably the most commonly used measure of amplifier noise performance. It can be expressed as the ratio of the noise power output of a network to the noise power output of an ideal noiseless network of otherwise identical characteristics when the input termination is at 290 K (as defined by the IEEE Standards on Electron Tubes). This is expressed mathematically in equation B-11.

$$F = \frac{N_o}{G_{sig}N_i} \quad (B-11)$$

Noise figure is also sometimes defined as the ratio of the input signal-to-noise ratio to the output signal-to-noise ratio when the input termination is at 290°K. This is expressed in equation B-12.

$$F = \frac{S_i/N_i}{S_o/N_o} \quad (B-12)$$

It can be seen that these two expressions are equivalent, if it is noted that

$$\frac{S_i}{S_o} = \frac{1}{G_{sig}} \quad (B-13)$$

Note also that noise figure is defined only for a two-port transducer. For the special case of a heterodyne system, the term $G_s N_i$ applies only to the principal frequency transformation and does not include spurious contributions such as those from an unused image-frequency or an unused idler-frequency transformation.

Noise figure can be related to effective input noise temperature by combining equations B-6 and B-11 and noting the restrictions cited above;

$$F = \left(\frac{T_o + T_e}{T_o} \right) \left(1 + \frac{G_{im}}{G_{sig}} \right) \quad (B-14)$$

where T_o = the reference temperature, 290°K

For a single-channel system, $G_{im} = 0$

and

$$F = \frac{T_e}{290} + 1 \quad (B-15)$$

The rest of this appendix assumes that the system under test is a single-channel, two-port system; however, if the system under test is a heterodyne system, the results should be adjusted in accordance with the second parenthetical term in equation B-14.

2. NOISE-TEMPERATURE MEASUREMENT THEORY

a. Y FACTOR

Most methods used to measure effective input noise temperature and noise figure do so by determining the change in system noise output power for a known change in input noise power. The input to the network under test is first connected to a termination at some temperature T_1 . An output reference level that is indicative of the noise power out of the system (N_{O1}) is then noted. Substituting the known value of T_1 for T_i in equation B-6, the expression for N_{O1} can be written:

$$N_{O1} = K (T_1 + T_e) G \quad (B-16)$$

The network input termination is then raised to a temperature T_2 by physically changing terminations, energizing a noise lamp, etc. The output indication will increase. The noise output power under this condition can be written:

$$N_{O2} = K (T_2 + T_e) G \quad (B-17)$$

An accurately known amount of attenuation is then inserted between the network output and the output level indicator. This attenuation is adjusted so that the output level is the same as the original reference level. The required amount of attenuation is equal to the ratio of N_{O2} to N_{O1} ; this ratio is called the Y-factor and can be expressed as

$$Y = \frac{N_{O2}}{N_{O1}} \quad (B-18)$$

b. EFFECTIVE INPUT NOISE TEMPERATURE

Once the Y factor has been measured, T_e can be computed by substituting equations B-16 and B-17 into B-18:

$$Y = \frac{T_2 + T_e}{T_1 + T_e} \quad (\text{B-19})$$

Solving equation B-19 for T_e :

$$T_e = \frac{T_2 - YT_1}{Y - 1} \quad (\text{B-20})$$

Temperature T_2 is a function of the type of noise generator used, and T_1 is generally assumed equal to room temperature for gas-discharge and temperature-limited diode noise generators. Thermal-noise generators, such as the AIL Types 07002 and 07004 hot-cold standard noise generators provide a cold-termination temperature T_1 near that of liquid nitrogen. Y factor is usually measured with a variable, calibrated, waveguide-beyond-cutoff attenuator in the intermediate frequency section of the measurement setup. This attenuator is generally calibrated in db, and the result must be converted to a power ratio prior to substitution into equation B-20.

c. NOISE FIGURE

The noise figure of the unit under test can be determined by substituting equation B-20 into equation B-15. The result is:

$$F = \frac{\frac{T_2}{290} - Y \frac{T_1}{290}}{Y - 1} + 1 \quad (\text{B-21})$$

This result does not account for the possible presence of an image. If the system does exhibit a significant response at an unused image frequency, then equation B-21 must be modified by multiplying by the parenthetical factor $(1 + G_{im}/G_{sig})$, as indicated in equation B-14.

When gas-discharge or temperature-limited diode noise generators are used, T_1 is quite often assumed to be equal to the reference temperature T_0 (290°K). Under this condition equation B-21 reduces to:

$$F = \frac{\frac{T_2}{T_0} - 1}{Y - 1} \quad (B-22)$$

This relation should be used with caution, particularly when the system under test is a very low noise device (see part 3a of this appendix).

The quantity in the numerator of equation B-22 is generally specified as a measure of the output capability of a noise generator. It is called the relative excess noise temperature or excess noise ratio, and it is most often expressed in db, as noted below.

$$T_{ex} \text{ (db)} = 10 \text{ Log } \left(\frac{T_2}{T_0} - 1 \right) \quad (B-23)$$

3. ACCURACY CONSIDERATIONS

a. TERMINATION TEMPERATURE

Equation B-22, which assumes a cold-termination temperature equal to 290 K, is almost universally used to calculate noise figure when gas-discharge or temperature-limited diode noise generators are employed. It forms the basis for the meter scaling of all automatic measurement instruments and many of the computational aids in use today. However, the cold-termination temperature of the noise generator types mentioned can differ quite significantly from 290 K for a variety of reasons; for instance, the DC power dissipation in an argon gas discharge lamp (typically about 20 watts) could be enough to heat the termination to several degrees above room temperature. In fact, actual room temperature is usually several degrees above 290 K (about 62° F).

The extent of the error caused by the use of equation B-22 can be seen by referring to Figure B-1. This plot gives the difference between the calculated noise figure obtained when using equation B-22 and when using the exact relation, equation B-21 (all quantities expressed in db). In Figure B-1, F_m is the measured noise figure, that is, that which would be calculated from equation B-22; δ is the correction to be applied to F_m to obtain the true noise figure F_a , that which would be calculated from equation B-21.

b. SECOND-STAGE NOISE

This is the name given to the effects of the second or following elements of a cascaded amplification system. In general, if the gain of the first stage is high, these effects will be small; however, if the second-stage noise figure is high and the first-stage gain is low, the contribution of the second stage to the overall measured noise temperature or noise figure can be significant.

A measurement system consisting of the device under test followed by a supplementary amplifier or test receiver can be considered a cascade. Consequently, it may be necessary to consider the noise performance of the test receiver and correct the measured result for its contribution.

Second-stage effects can be evaluated as follows: The noise-power output per unit bandwidth of the device under test is given by equation B-6 (ignoring multiple responses):

$$N_{o1} = K(T_i + T_{e1}) G_1 \quad (B-24)$$

where the subscripts (1) refer to the first stage. Noting that,

$$T_{e1} = (F_1 - 1) T_o \quad (B-25)$$

and assuming that $T_i = T_o$,

$$N_{o1} = KG_1 F_1 T_o \quad (B-26)$$

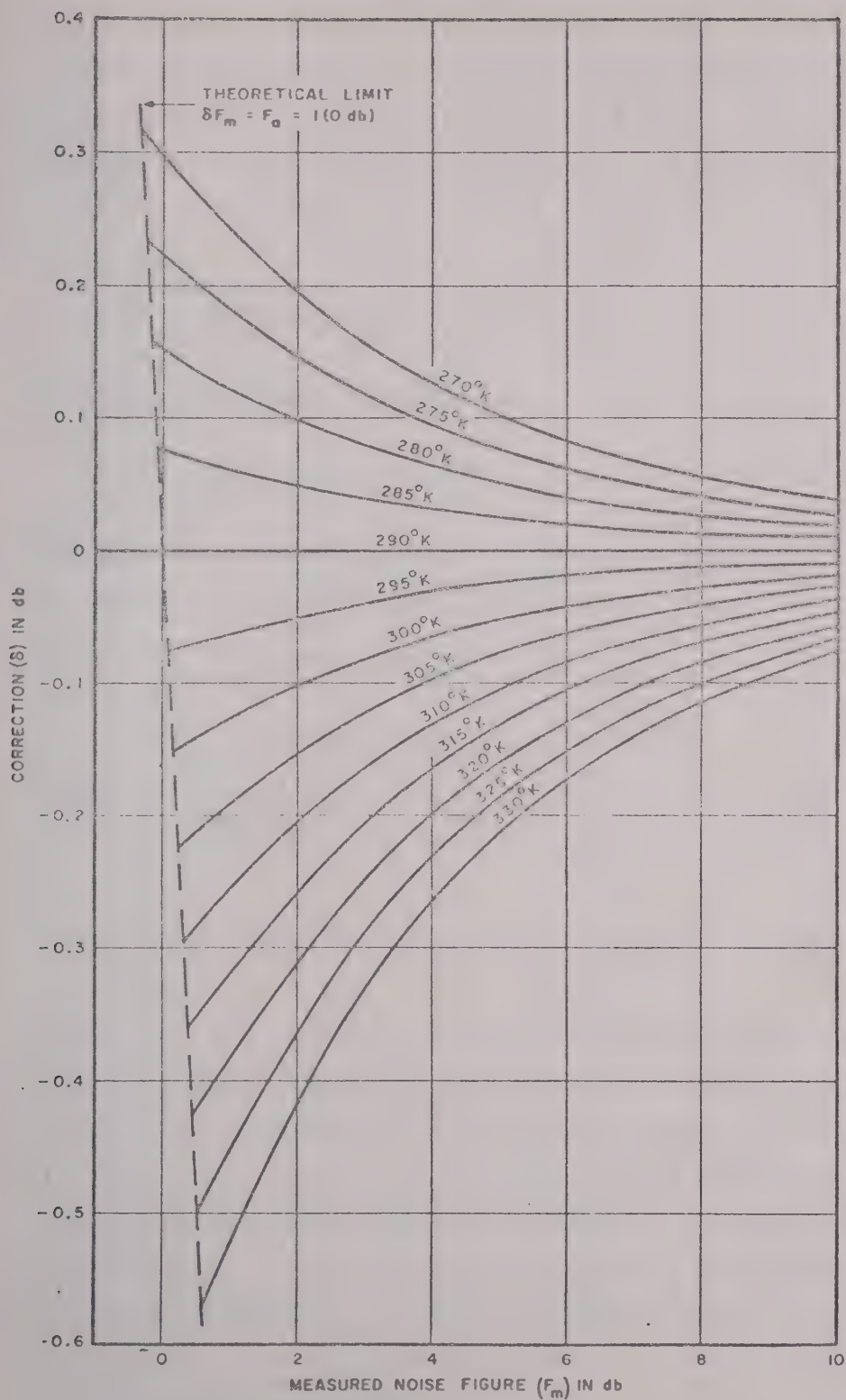


FIGURE B-1. CORRECTION FOR $T_1 \neq T_0$ (TERMINATION TEMPERATURE)

The noise-power output of the overall system would be the output of the first stage plus the internal noise of the second stage, referred to its input, amplified by the gain of the second stage. The internal noise of the second stage, referred to its input, is simply KT_{e2} or $K(F_2 - 1) T_o$. Therefore,

$$N_{o2} = G_2 \left[N_{o1} + K(F_2 - 1)T_o \right] \quad (B-27)$$

Substituting equation B-26 into this,

$$N_{o2} = G_2 K T_o \left[F_1 G_1 + (F_2 - 1) \right] \quad (B-28)$$

The total noise output N_{o2} of the system can, by definition, be written in terms of an overall or system noise figure:

$$N_{o2} = K G_1 G_2 F_{1-2} T_o \quad (B-29)$$

where, F_{1-2} = overall system noise figure.

Equating B-28 and B29

$$K G_1 G_2 F_{1-2} T_o = G_2 K T_o \left[F_1 G_1 + (F_2 - 1) \right] \quad (B-30)$$

and

$$F_{1-2} = F_1 + \frac{F_2 - 1}{G_1} \quad (B-31)$$

The quantity $(F_2 - 1/G_1)$ is the contribution of the second stage to the overall or measured noise figure. It can be seen, then, that if the second-stage noise figure is high and/or the first-stage gain is low, this contribution could be significant. Figure B-2 is a nomograph of equation B-31, and it can be used to determine the extent of these effects. The value of F_{1-2} is the noise figure that would be measured for the system. ϵ_{db} is the correction to be added algebraically to F_{1-2} (in db) to obtain the first stage noise figure F_1 .

c. BANDWIDTH EFFECTS

The total noise power available in an amplifying or receiving system is actually characterized by its noise temperature or noise figure averaged

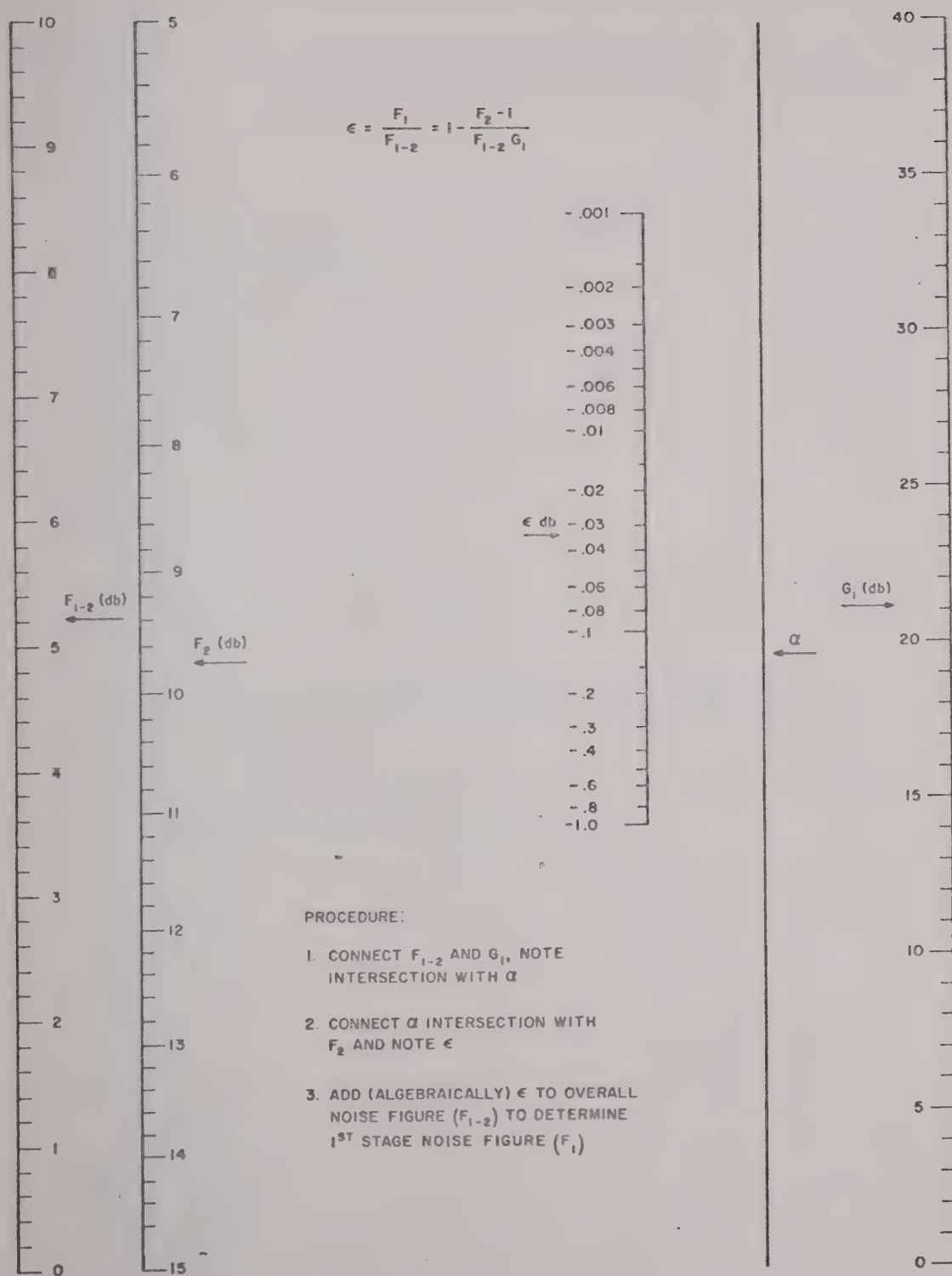


FIGURE B-2. NOMOGRAPH, CORRECTION FOR SECOND-STAGE NOISE FIGURE

over its bandwidth. Since a signal must compete with this total noise rather than noise at a single frequency, it is these average quantities that are of major interest to the system designer.

If the bandwidth of the measuring system is slightly greater than that of the system under test, then the procedures indicated will yield average noise figure or noise temperature directly. If, however, the measurement bandwidth is narrow with respect to the system bandwidth, then the quantity measured approximates what is called spot noise figure or temperature. An accurate determination of the noise performance of the system then requires several measurements averaged over the band.

4. REFERENCES

- a. Haus, et. al., IRE Standards on Electron Tubes: Definitions of Terms, 1962* (62 IRE 7.S2) Proceedings of the IEEE, 434-435, March 1963.
- b. Haus, et.al., "Description of the Noise Performance of Amplifiers and Receiving Systems," Proceedings of the IEEE, 436-442, March 1963.
- c. M. Lebenbaum, "Measurement of Noise Figure," Handbook of Electronic Measurements, Vol. II, Chap. XI, p 1-51, Polytechnic Institute of Brooklyn, 1956.

APPENDIX C

AUXILIARY EQUIPMENT

TABLE C-1
MIXERS, COAXIAL

<u>Frequency Range (MHz)</u>	<u>AIL Part Number</u>
40-150	13635*
125-500	13510
500-1000	13503
1000-2000	13504
2000-4000	13505
4000-8000	13506
7000-11000	13507

*Note: Includes tunable local oscillator. Useful only with low-noise preamplifier (AIL part number 13630).

TABLE C-2
MIXERS, WAVEGUIDE

<u>Frequency Range (GHz)</u>	<u>AIL Part Number</u>
4.4 - 5.0	13523
5.4 - 5.9	13524
5.9 - 6.4	13525
8.5 - 9.6	13528
12.4 - 14.0	13532
15.0 - 17.0	13534
23.0 - 25.0	13538
34.0 - 36.0	13539

TABLE C-3
NOISE GENERATORS AND TERMINATIONS

<u>Frequency Range</u>	<u>Type</u>	<u>Part No.</u>	<u>Termination AIL part No.</u>
0-2.0 GHz	Hot/cold standard	07002	---
0-6.0 GHz	Hot/cold standard	07004	---
10-250 MHz	Diode	07006	---
0.2-2.6 GHz	Coaxial	07010	---
2.0-5.0 GHz	Coaxial	07012	---
30/60 MHz	Diode, Multiple Impedance	07008	---
2.6-3.95 GHz	Waveguide	07048	207295-1
3.95-5.85 GHz	Waveguide	07049	207295-2
5.85-8.2 GHz	Waveguide	07050	207295-3
7.05-10.0 GHz	Waveguide	07051	207295-4
8.2-12.4 GHz	Waveguide	07052	207295-5
12.4-18.0 GHz	Waveguide	07053	207295-6
18.0-26.5 GHz	Waveguide	07091	207295-7
26.5-40.0 GHz	Waveguide	07096	---

